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Compliance Monitoring Plan for the Lawrence Livermore National Laboratory Livermore Site

Technical Editors

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January 29, 1996

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Environmental Protection Department

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Summary

Ground water and unsaturated sediment (sediment above the water table where pore spaces are only partially filled with water) at the Lawrence Livermore National Laboratory (LLNL) Livermore Site contain volatile organic compounds, fuel hydrocarbons, metals, and tritium. Remedial activities have been initiated at the Livermore Site to reduce compounds of concern below State and Federal Maximum Contaminant Levels, and to prevent further migration of the affected ground water. Currently, five ground water treatment facilities are extracting and treating ground water and one facility extracts and treats soil vapor. Four additional ground water treatment facilities and one vapor treatment facility are planned for operation in the future.

This Compliance Monitoring Plan describes remediation monitoring, and data management, evaluation, and reporting that will be used to:

- Examine to what extent cleanup goals have been achieved, and to determine when specific cleanup actions should cease.
- Evaluate the effectiveness of remedial actions, indicate deviations from expected performance, and indicate remediation modifications to achieve cleanup goals in the most expedient manner that funding allows.

Data on chemical, hydraulic, and subsurface material properties are required to track the progress of remedial actions and to monitor the site after active remediation ceases. Using these data, several remediation performance measures will be tracked. The three-dimensional region of hydraulic capture around extraction wells will be estimated using the hydraulic head distribution determined from water level measurements. Chemical distribution in the subsurface will continue to be estimated by using site-specific data in various interpolations. Chemical distribution will be used to estimate the contaminant mass remaining in the subsurface. Mass removal and total flow rates from extraction wells will be used to assess treatment facility effectiveness and the progress of cleanup.

The data collected and the interpretations developed during the Livermore Site remediation will be used to update subsurface conceptual and computational models. These models will be used to periodically re-evaluate the remediation plans, define project completion, determine when project goals have been achieved, create visualizations to convey information on cleanup progress to the regulatory agencies and public, and determine when active remediation should cease.

This Compliance Monitoring Plan establishes the guidelines to monitor remediation, and also presents reporting frequencies and mechanisms. Appendix A lists the LLNL Environmental Restoration Division’s Standard Operating Procedures. Appendix B lists wells monitored at the Livermore Site grouped by hydrostratigraphic unit. Algorithms for determining sampling schedules for ground water and soil vapor are presented in Appendices C and D, respectively. Appendix E presents the Livermore Site’s current reporting requirements. This Compliance Monitoring Plan and accompanying algorithms are designed to be flexible to accommodate changes in technology, regulations, and site-wide chemical distribution that occur over the course of the cleanup.

1. Introduction

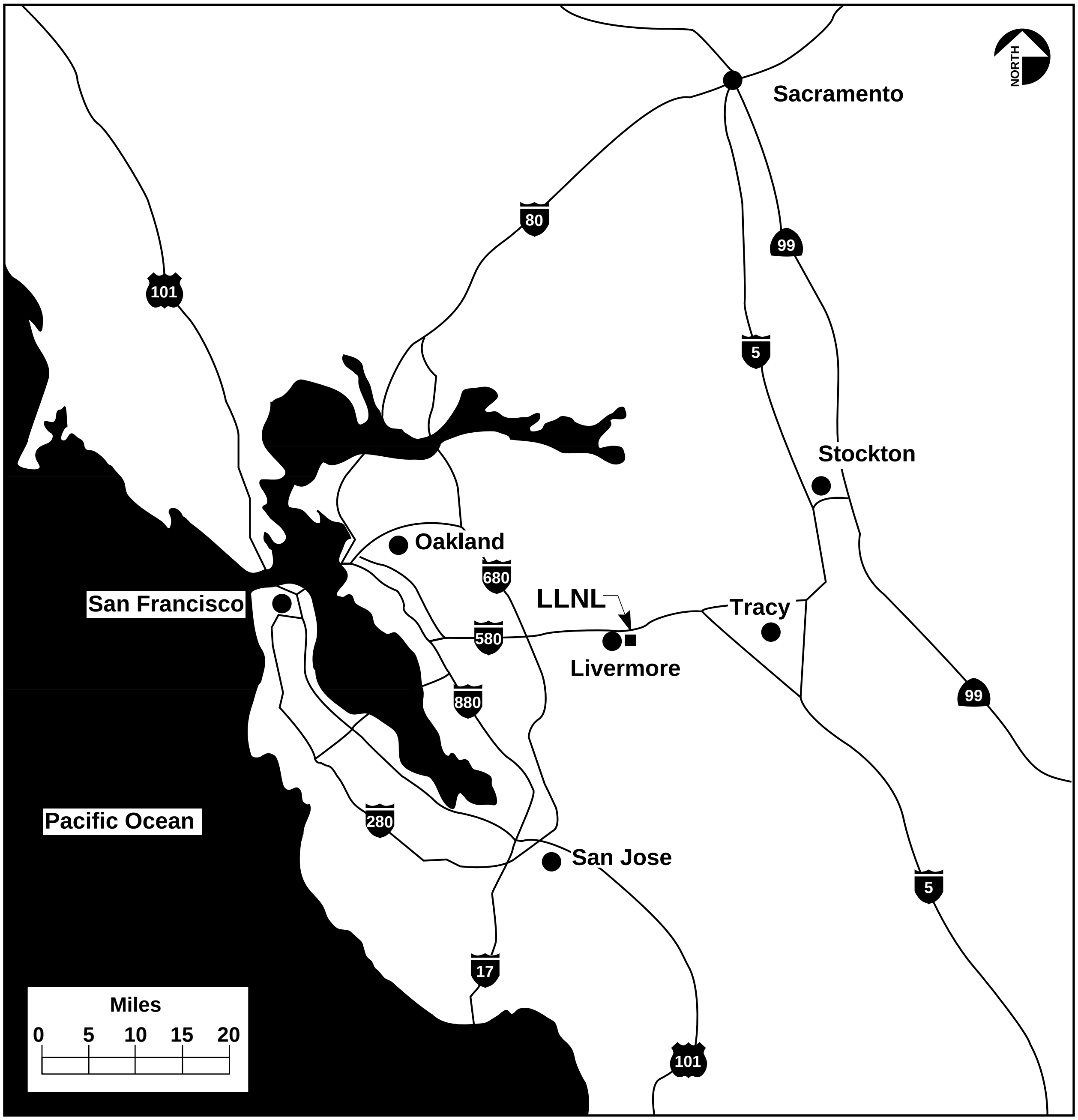
This Compliance Monitoring Plan (CMP) for the Lawrence Livermore National Laboratory (LLNL) Livermore Site was prepared to comply with requirements of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). This report describes the procedures to monitor ground water and vadose zone remediation, manage data, and report remedial activities and results. It also discusses the methods used to interpret and assess the progress of the Livermore Site remedial objectives stated in the Record of Decision (ROD) [U.S. Department of Energy (DOE), 1992]. This CMP is intended to be a flexible document that will accommodate changes in technology and regulations that are likely to occur over the course of the cleanup.

Because no guidance documents for a CMP are currently available, this report follows concepts discussed by the U.S. Environmental Protection Agency (EPA) (1992a, 1992b, 1993, 1994), Gorelick *et al.* (1994), Hoffman (1993), and Keely (1989).

Livermore Site soil and ground water remediation will be implemented by operating eight ground water treatment facilities, one vapor extraction facility, and one combined ground water and vapor treatment facility. The baseline estimates [estimated volatile organic compound (VOC) volumes removed over time] for nine of these facilities were discussed in associated Remedial Design (RD) reports, and are included in this plan. Baseline estimates for the other two facilities will be presented in a forthcoming RD report. Section 1 of this report summarizes background information on the Livermore Site. Section 2 describes remediation objectives and implementation. Section 3 describes data collection. Sections 4 through 6 discuss data collection management, quality assurance, and analysis. Sections 7 and 8 describe reporting and budget issues. Appendix A lists the LLNL Environmental Restoration Division's (ERD's) Standard Operating Procedure (SOP) titles. Appendix B lists wells monitored at the Livermore Site grouped by hydrostratigraphic units (HSUs). Appendices C and D present algorithms for determining cost-effective monitoring frequencies for ground water and soil vapor, respectively. Appendix E presents LLNL's current reporting requirements.

1.1. Background

The LLNL Livermore Site is located about 40 miles east of San Francisco, California (Fig. 1). Initial releases of hazardous materials occurred at the LLNL Livermore Site in the mid- to late 1940s when the site was operated as the U.S. Livermore Naval Air Station (Thorpe *et al.*, 1990). Evidence also indicates that localized spills, leaking tanks and impoundments, and landfills contributed VOCs, fuel hydrocarbons (FHCs), manganese, chromium, and tritium to ground water and unsaturated sediments in the post-Navy era. Screening of all environmental media indicates that ground water and unsaturated sediment are the only media that require remediation (Thorpe *et al.*, 1990). The identified chemicals that have existed in ground water at various locations beneath the site in concentrations above drinking water standards are:



CMP-95-Fig01

Figure 1. Location of the LLNL Livermore Site.

- VOCs—trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), chloroform, 1,2-dichloroethylene (1,2-DCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), trichlorotrifluoroethane (Freon 113), trichlorofluoromethane (Freon 11), 1,1,1-trichloroethane (1,1,1-TCA), and carbon tetrachloride.
- FHCs—benzene, ethylbenzene, toluene, and ethylene dibromide.
- Metals—chromium and manganese. Subsequent to the ROD, localized nickel in concentrations above the Maximum Contaminant Level (MCL) were detected in the east-central part of the site.
- Radionuclides—tritium.

For the purposes of this plan, the term compounds of concern (COC) will be used to refer to all compounds above MCLs at the Livermore Site, unless an individual chemical species is specified.

LLNL has completed several CERCLA reports for soil and ground water remediation at the Livermore Site. These reports include the Remedial Investigation (Thorpe *et al.*, 1990), a Feasibility Study (FS) (Isherwood *et al.*, 1990), the ROD (U.S. DOE, 1992), a Remedial Action Implementation Plan (RAIP) (Dresen *et al.*, 1993), and five RD Reports (Boegel, *et al.*, 1993; Berg *et al.*, 1993; Berg *et al.*, 1994a; Berg *et al.*, 1994b; Berg *et al.*, 1995). As presented in the RAIP (Dresen *et al.*, 1993), three other post-ROD documents include this CMP, a forthcoming Contingency Plan, and a forthcoming RD Report for ground water and vapor treatment at Trailer 5475 .

1.2. Remedial Objectives and Activities

Remediation was initiated in 1992 at the Livermore Site to meet the objectives of the ROD. Five ground water treatment facilities are currently extracting and treating ground water. Four additional ground water treatment facilities and one vapor treatment facility are planned for the future.

1.2.1. Remediation Objectives

As defined in the ROD, the remediation objectives for the Livermore Site are to:

- Prevent future human exposure to contaminated ground water and soil.
- Prevent further migration of COCs in ground water (henceforth referred to as the "plume") in concentrations above MCLs.
- Reduce COC concentrations in ground water to levels below the State and Federal MCLs, and reduce the COC concentrations in treated ground water to levels below State discharge limits.
- Prevent migration in the unsaturated zone of those COCs that would result in concentrations in ground water above an MCL.
- Meet all discharge standards of existing permits for treated water and treated soil vapor.

1.2.2. Summary of Previous Activities

The FS (Isherwood *et al.*, 1990) evaluated potential remedies for the Livermore Site ground water plume and the portion of unsaturated zone requiring remediation. Three alternatives were evaluated for the ground water plume, and two potential remedies were evaluated for the unsaturated zone.

The selected remedy for ground water is summarized below:

1. Ground water will be extracted at 24 initial locations to contain and remediate the ground water plume (Fig. 2). Ground water will be pumped from one or more wells at each of these locations using existing monitor and extraction wells along with new extraction wells. The highest priority wells are being installed at or near downgradient plume margins to contain and prevent further migration of ground water containing VOCs in concentrations above MCLs. To enable more rapid remediation, some of the wells will be placed in areas with concentrations greater than about 100 parts per billion (ppb) VOCs or FHCs. The extraction locations may be augmented if field data indicate that additional wells are needed to meet ROD objectives, and/or that new pumping locations will accelerate the cleanup.
2. Treatment Facilities A through G, and a facility for the Trailer 5475 Area, have been, or will be constructed to treat the extracted ground water. Each treatment system is designed to treat the specific COCs from the associated extraction wells.
3. Ultraviolet (UV)/oxidation-based remediation technology is used to treat VOCs at Treatment Facilities A and B (and is planned for E), and to treat FHCs and VOCs at Treatment Facility F. Treatment Facilities C and D (and is planned for G) use air stripping-based technology, which is more effective on the higher concentrations of COCs in the area of those facilities (chloroform, carbon tetrachloride, Freon 113, Freon 11, and 1,1,1-TCA). Due to the presence of both tritium and VOCs, the Trailer 5475 facility may consist of UV/oxidation to destroy TCE, PCE and 1,1-DCE, and a closed-loop air stripping system to remove residual VOCs. Treated water containing tritium will be reinjected.

The selected remedy for the unsaturated zone is soil vapor extraction and treatment, using vacuum pumps to extract COCs in the vapor phase from the unsaturated sediments, and treating the vapor with granular activated carbon (GAC). Soil vapor extraction and treatment have been used at Treatment Facility F and Treatment Facility 518 (TF-518), and are planned for the Trailer 5475 Area.

Effluent from each treatment facility will comply with Regional Water Quality Control Board Waste Discharge Requirements and/or Bay Area Air Quality Management District air permit requirements. The treatment facilities are briefly described below and summarized in Table 1.

1.2.2.1. Treatment Facility A (TFA)

TFA, located in the southwest quadrant of the Livermore Site (Fig. 2), began operation as a pilot study in April 1989. Extracted ground water is treated by UV/oxidation and air stripping, then discharged to the Recharge Basin south of East Avenue (Fig. 2), or used for onsite irrigation or in cooling towers. The baseline estimates versus actual VOC volume removed to date for

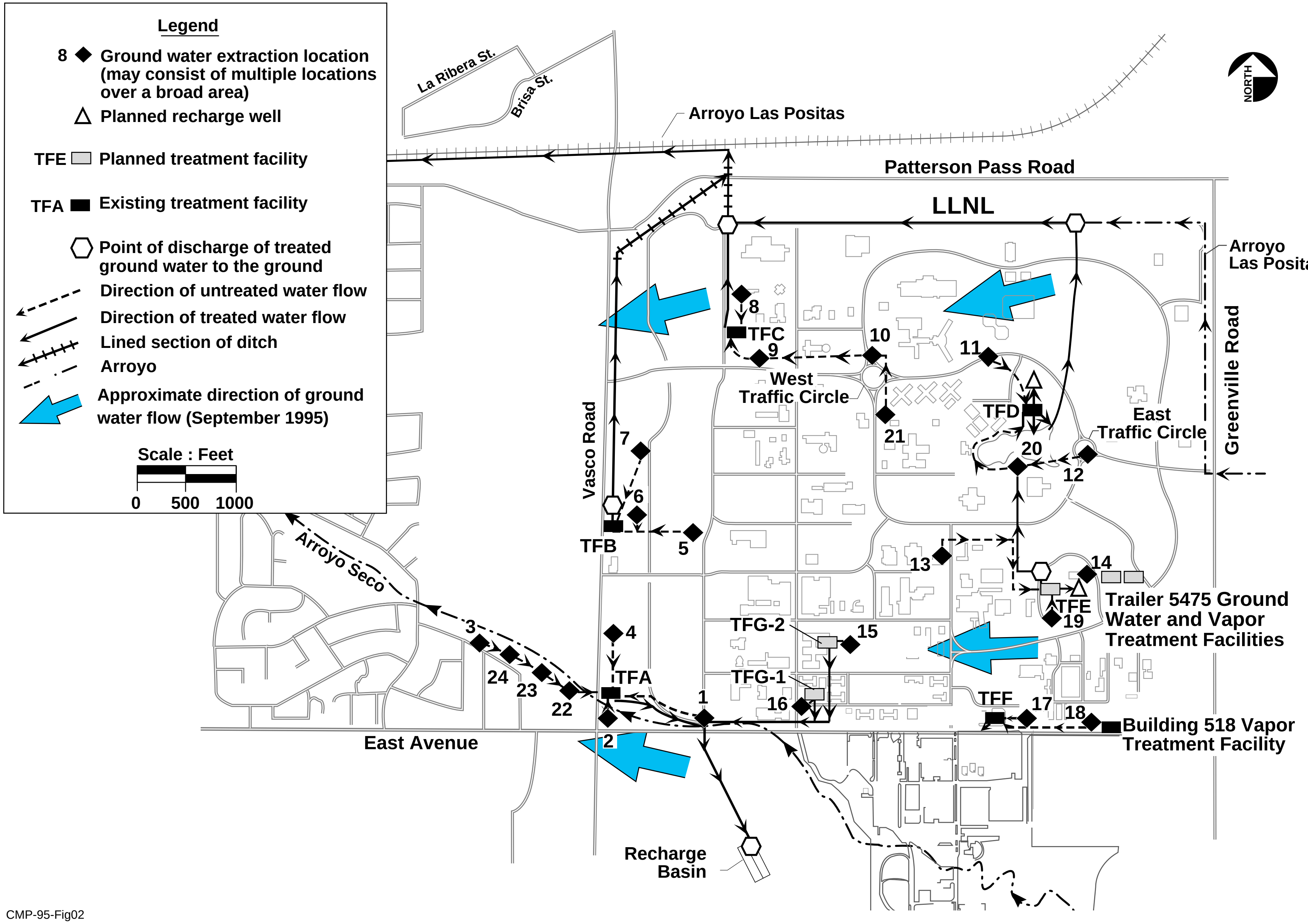


Figure 2. Planned and existing ground water and soil vapor treatment facilities at the Livermore Site.

Table 1. Treatment facility summary.

Facility	Media treated	Contaminants	Technology	Discharge location	Applicable permit(s)
Treatment Facility A	Ground water	VOCs	UV/oxidation; air stripping with GAC	Recharge Basin	RWQCB WDR 88-075; BAAQMD[1]
Treatment Facility B	Ground water	VOCs	UV/oxidation; air stripping with GAC	North-flowing drainage ditch that flows to Arroyo Las Positas	RWQCB WDR 91-091; BAAQMD[1]
Treatment Facility C	Ground water	VOCs; hexavalent chromium	Air stripping with GAC; ion exchange	North-flowing ditch that flows to Arroyo Las Positas	RWQCB WDR 91-091; BAAQMD[1]
Treatment Facility D	Ground water	VOCs; hexavalent chromium	Air stripping with GAC; ion exchange	North-flowing pipeline that empties into Arroyo Los Positas or the Drainage Retention Basin	RWQCB WDR 91-091; BAAQMD[1]
Treatment Facility E	Ground water	VOCs	UV/oxidation; air stripping with GAC	Drainage Retention Basin[3]	RWQCB WDR 91-091; BAAQMD[2]
Treatment Facility F	Ground water	FHCs; VOCs	UV/oxidation; air stripping with GAC	Sanitary sewer	City of Livermore Permit No. 1508G;
	Soil vapor	FHCs	GAC with steam regeneration	Atmosphere	BAAQMD[1]
Treatment Facility G-1	Ground water	VOCs; possibly hexavalent chromium	Air stripping with GAC; ion exchange[4]	Storm drain or Recharge Basin	RWQCB WDR 91-091; BAAQMD[2]
Treatment Facility G-2	Ground water	VOCs; possibly hexavalent chromium	Air stripping with GAC; ion exchange[4]	Storm drain or Recharge Basin	RWQCB WDR 91-091; BAAQMD[5]
Building 518 Vapor Treatment Facility	Soil vapor	VOCs	GAC	Atmosphere	BAAQMD[1]
Trailer 5475 (water)	Ground water	VOCs; tritium	Currently being evaluated	Reinjection	RWQCB WDR 91-091; BAAQMD[5]
Trailer 5475 (vapor)	Soil vapor	VOCs; tritium	Currently being evaluated	Reinjection	BAAQMD[5]

Abbreviations:

BAAQMD = Bay Area Air Quality Management District.
GAC = Granular Activated Carbon.
RWQCB = Regional Water Quality Control Board.
WDR = Waste Discharge Requirements.

Notes:

1 BAAQMD Permit to Operate.
2 BAAQMD Authority-to-Construct.
3 As stated in Remedial Design Report No. 3 (Berg *et al*., 1994a).
4 Ion exchange or a hexavalent chromium reduction unit, if required.
5 BAAQMD Authority-to-Construct will be obtained.

TFA are presented in Figure 3. VOC volume removal estimates are discussed further in Boegel *et al.* (1993). By September 1995, over 156 million gallons of extracted ground water have been treated, removing approximately 56.5 kg (9.6 gal) of VOCs.

1.2.2.2. Treatment Facility B (TFB)

TFB, located north of TFA (Fig. 2), began operation as a pilot study in July 1990. Extracted ground water is treated by UV/oxidation and air stripping, then discharged to a drainage ditch that flows to Arroyo Las Positas in the northwest corner of the site. The baseline estimates versus actual VOC volume removed to date for TFB are presented in Figure 4. VOC volume removal estimates and are discussed further in Boegel *et al.* (1993). By September 1995, over 30 million gallons of extracted ground water have been treated, removing approximately 11.3 kg (2 gal) of VOCs.

1.2.2.3. Treatment Facility C (TFC)

TFC, located in the northwest quadrant of the Livermore Site (Fig. 2), began operation in October 1993. Extracted ground water is treated by air stripping and ion exchange, then discharged to a north-flowing pipeline that empties into Arroyo Las Positas. The baseline estimates versus actual VOC volume removed to date for TFC are presented in Figure 5.

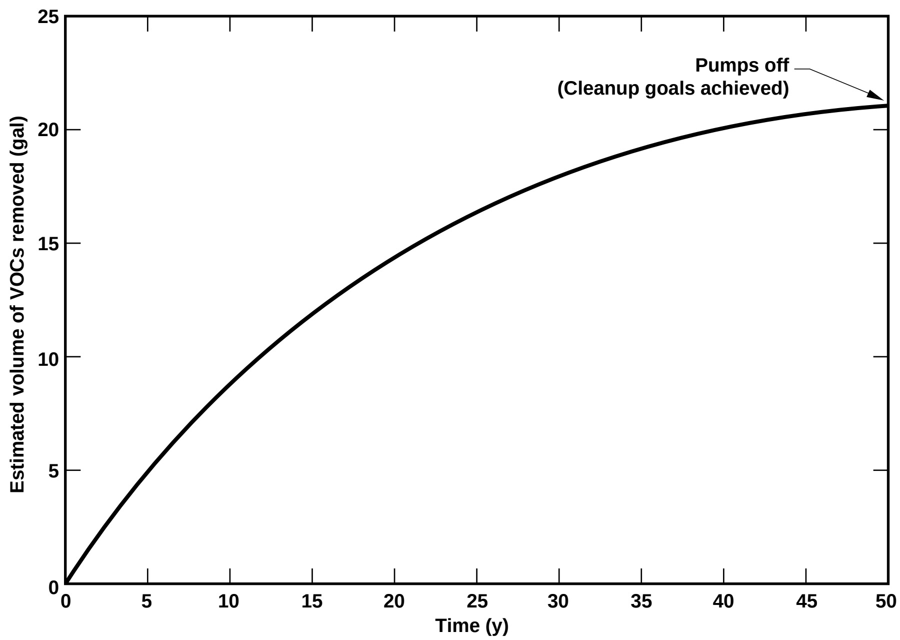
As shown in Figures 3, 4, and 5, actual VOC volume removal rates are greater than those estimated from the two-dimensional model. Two primary reasons for this difference are: (1) the concentrations of total VOCs were averaged over the entire thickness of the area specified in the two-dimensional model, which tends to “dilute” the model concentration, suggesting that less mass is removed; and (2) not all of the VOC mass was incorporated into the model since Freon 11, Freon 113, and 1,1,1-TCA were not included in the two-dimensional model mass estimate. Although Freon 113 is not currently present in concentrations above its MCL, it comprises about 70 percent of the VOC volume removed at TFC, which makes a more substantial difference between the model estimate and the actual mass removed. VOC volume removal estimates are discussed further in Berg *et al.* (1993). By September 1995, approximately 7 million gallons of extracted ground water have been treated, removing approximately 3.3 kg (0.6 gal) of VOCs.

1.2.2.4. Treatment Facility D (TFD)

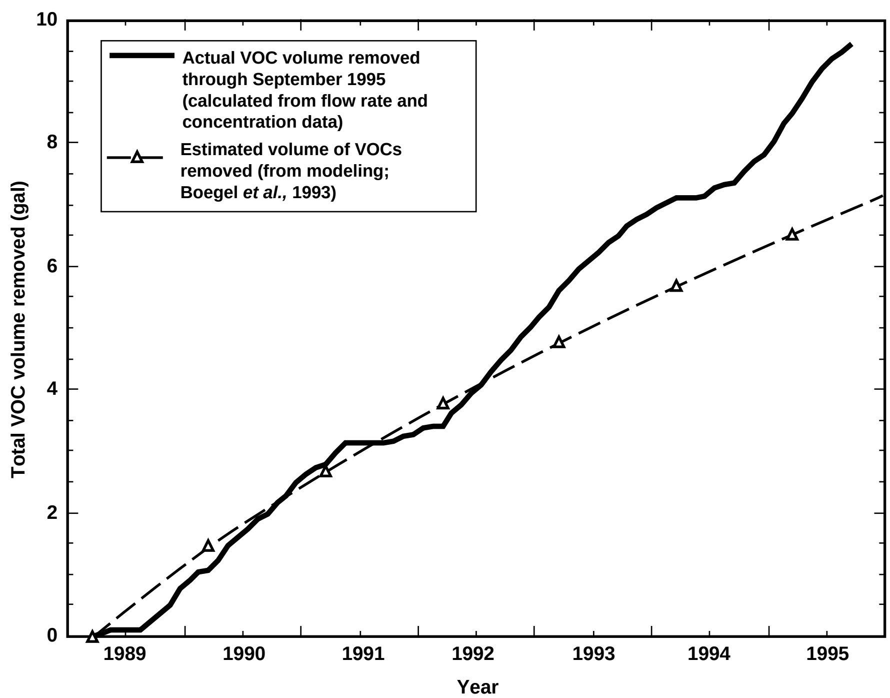
TFD, located in the northeastern quadrant of the Livermore Site (Fig. 2), began operation in September 1994. Ground water is treated by air stripping and ion exchange prior to discharge to the Drainage Retention Basin or to a north-flowing pipeline that empties into Arroyo Las Positas. The baseline estimates versus actual VOC volume removed to date for TFD are presented in Figure 6. VOC volume removal estimates are discussed further in Berg *et al.* (1994a). By September 1995, approximately 1.6 million gallons of extracted ground water have been treated, removing approximately 5 kg (0.9 gal) of VOCs.

1.2.2.5. Treatment Facility E (TFE)

The planned location for TFE is in the southeast quadrant of the Livermore Site (Fig. 2). The TFE design was presented in Berg *et al.* (1994a). TFE will treat ground water containing VOCs



a. Estimated cumulative volume of VOCs that may be removed from ground water at TFA over time (Boegel *et al.,* 1993).



b. Actual versus estimated volume of VOCs removed at TFA.

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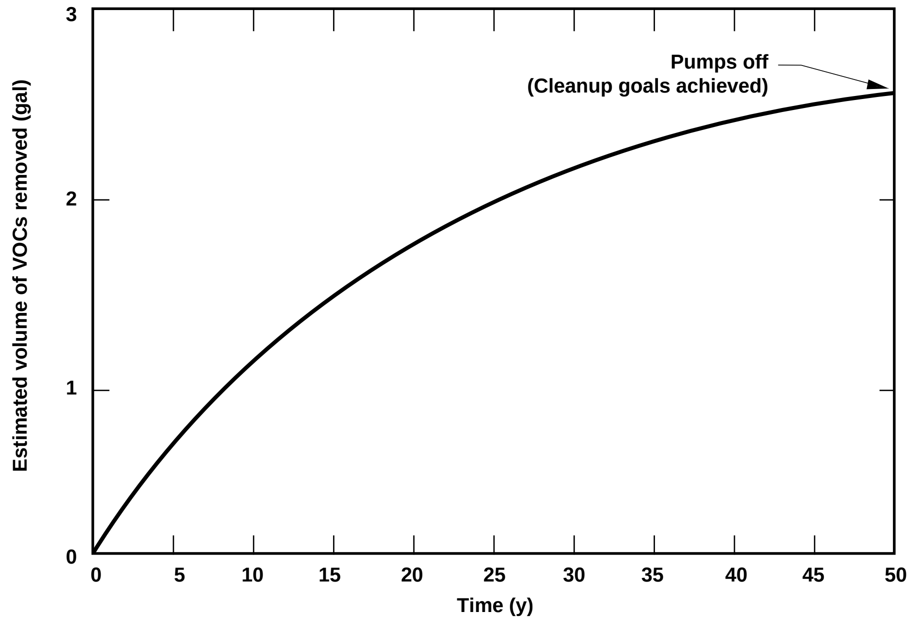
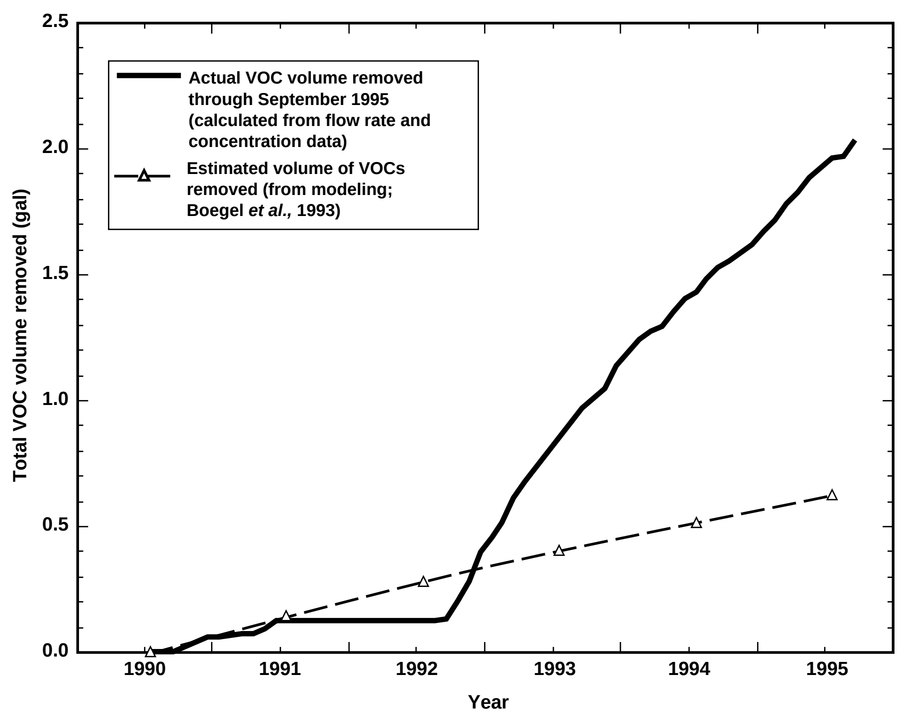
Figure 3. Estimated and actual cumulative volume of VOCs that may be removed from ground water by TFA over time.



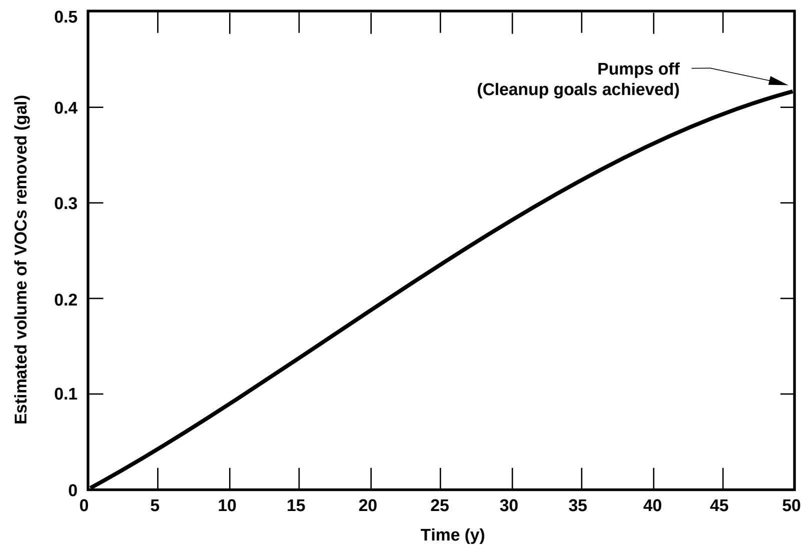
a. Estimated cumulative volume of VOCs that may be removed from ground water at TFB over time (Boegel *et al.,* 1993).



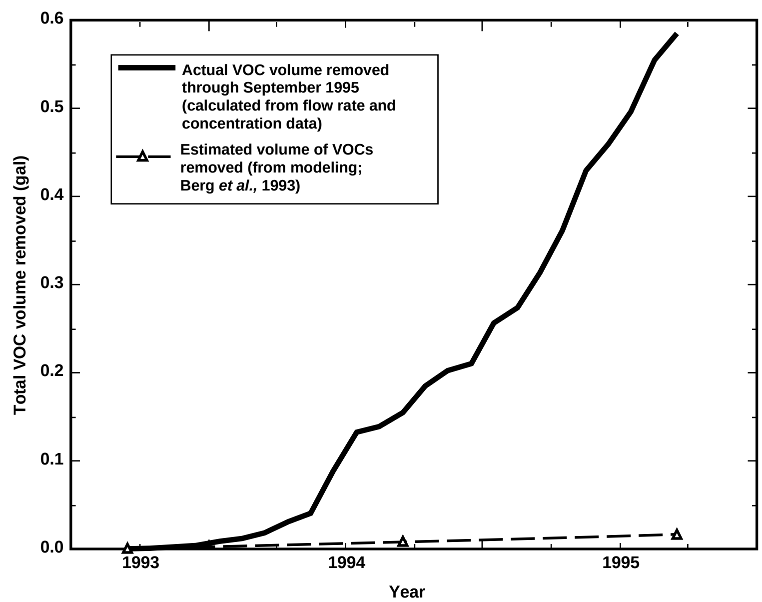
b. Actual versus estimated volume of VOCs removed at TFB.

CMP-95-Fig04

Figure 4. Estimated and actual cumulative volume of VOCs that may be removed from ground water by TFB over time.



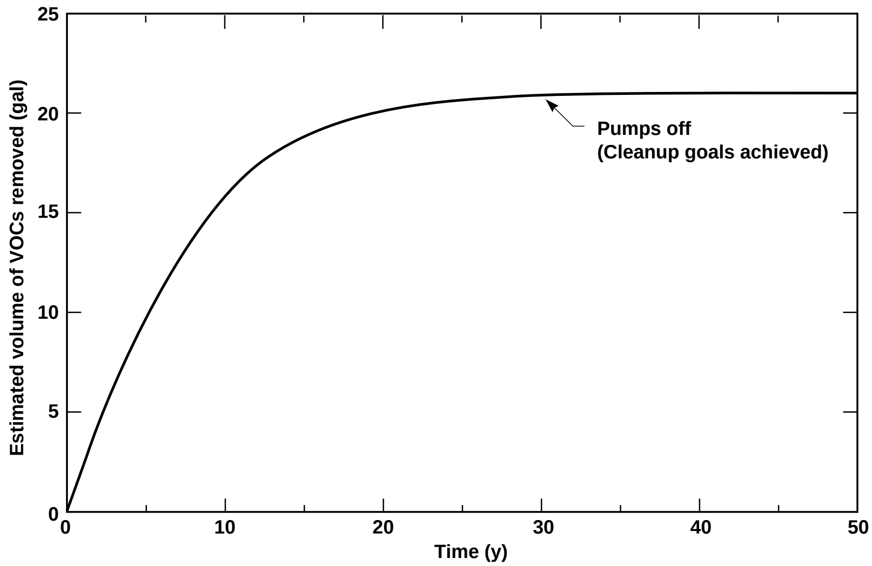
a. Estimated cumulative volume of VOCs that may be removed from ground water at TFC over time (Berg *et al.,* 1993).



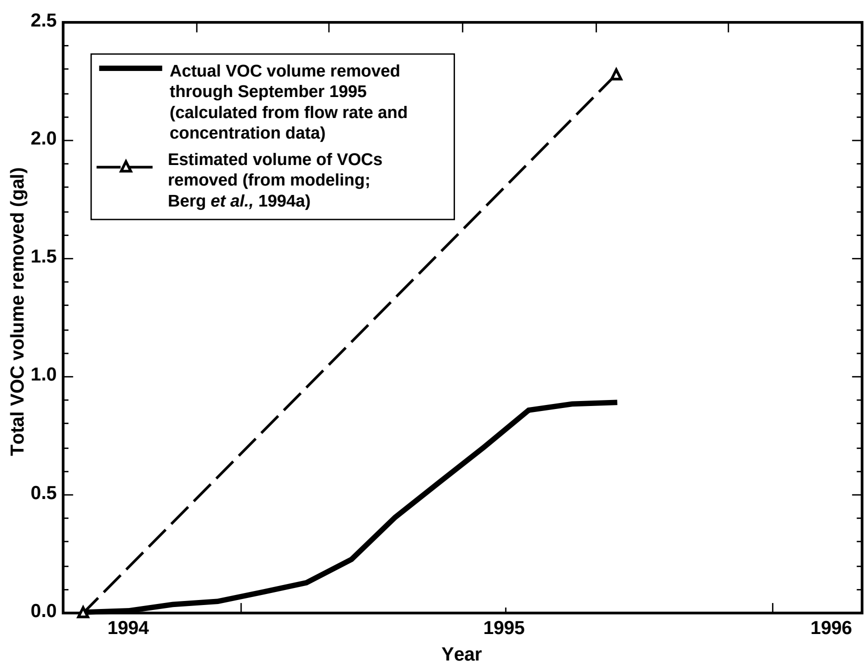
b. Actual versus estimated volume of VOCs removed at TFC.

CMP-95-Fig05

Figure 5. Estimated and actual cumulative volume of VOCs that may be removed from ground water by TFC over time.



a. Estimated cumulative volume of VOCs that may be removed from ground water at TFD over time (Berg *et al.*, 1994a).



b. Actual versus estimated volume of VOCs removed at TFD.

CMP-95-Fig06

Figure 6. Estimated and actual cumulative volume of VOCs that may be removed from ground water by TFD over time.

by UV/oxidation and air stripping, and is scheduled to begin operation in September 1999. The baseline estimates for TFE are presented in Figure 7, and VOC volume removal estimates are discussed further in Berg *et al.* (1994a).

1.2.2.6. Treatment Facility F (TFF)

TFF is located in the Gasoline Spill Area along the southern boundary of the Livermore Site (Fig. 2). In 1988, soil vapor treatability tests began and successfully removed about 2,000 gallons of liquid equivalent FHCs. Soil heating and steam injection have been used as a demonstration project in the TFF Area to remove free-phase FHCs (Yow *et al.*, 1994). TFF began operation in February 1993. Ground water extracted from this area is treated by UV/oxidation and air stripping, and extracted vapor is treated with GAC. Current plans include installing deeper wells to treat a deeper HSU containing VOCs. The ground water VOC baseline estimates for TFF are presented in Figure 8, and VOC volume removal estimates are discussed further in Berg *et al.* (1993). From 1993 through September 1995, over 15.8 million gallons of ground water and 42.5 million cubic feet of FHC-bearing vapor have been treated, removing about 7,500 gallons of FHCs for a total of approximately 9,500 gallons.

1.2.2.7. Treatment Facility G (TFG)

The TFG Area, located in the southwest quadrant of the Livermore Site (Fig. 2), is in a high-security area of the Livermore Site that is extensively developed with buildings and underground utilities. Thus, for logistical and practical purposes, ground water containing VOCs will be treated at two separate portable treatment units. Ground water extracted from location 15 will be treated at TFG-2, and ground water extracted from location 16 will be treated at TFG-1 (Fig. 2). Ground water will be treated by air stripping and, if hexavalent chromium is present at concentrations above discharge levels, an ion-exchange unit or a hexavalent chromium reduction unit may be used to reduce chromium concentrations below the discharge limit. TFG-1 is scheduled to begin operation in April 1996, and TFG-2 is scheduled to begin operation in August 1999. The baseline estimates for TFG-1 and TFG-2 are presented in Figures 9 and 10, respectively, and VOC volume removal estimates are discussed further in Berg *et al.* (1995).

1.2.2.8. Building 518 Vapor Treatment Facility

TF-518 is located in the southeast quadrant of the Livermore Site, east of TFF (Fig. 2), and began operation in September 1995. VOCs in extracted soil vapor are removed by GAC. The baseline estimates for TF-518 are presented in Figure 11, and VOC volume removal estimates are discussed further in Berg *et al.* (1994b). By the end of September 1995, approximately 6,800 cubic feet of vapor was extracted and treated, removing approximately 0.7 kg (0.1 gal) of VOCs.

1.2.2.9. Trailer 5475 Treatment Facilities

Two separate treatment facilities will be located at Trailer 5475 in the southeast quadrant of the Livermore Site (Fig. 2). These facilities will consist of a ground water treatment facility and a vapor treatment system. The RD report that will include the baseline estimates for these facilities is scheduled to be issued in July 1997. The ground water and vapor treatment facilities are scheduled to begin operation on September 30, 1998 and June 29, 1999, respectively.

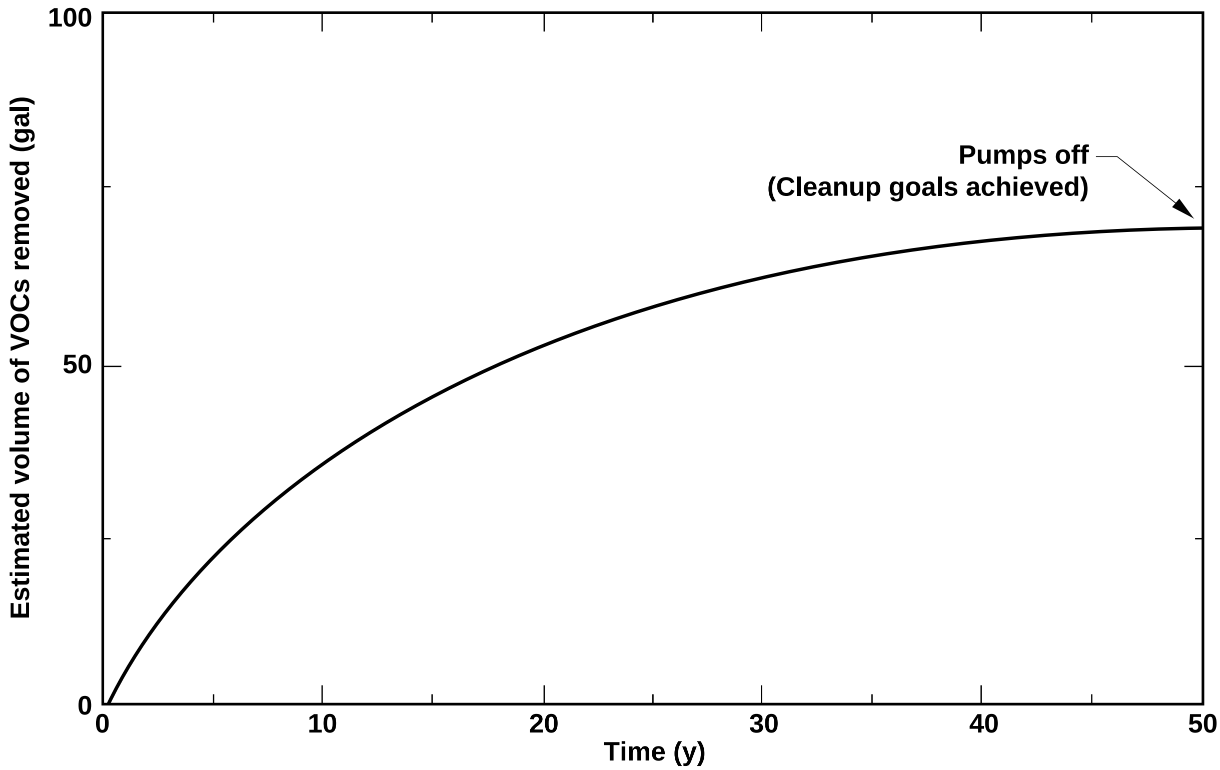


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Figure 7. Estimated cumulative volume of VOCs that may be removed from ground water by TFE over time.

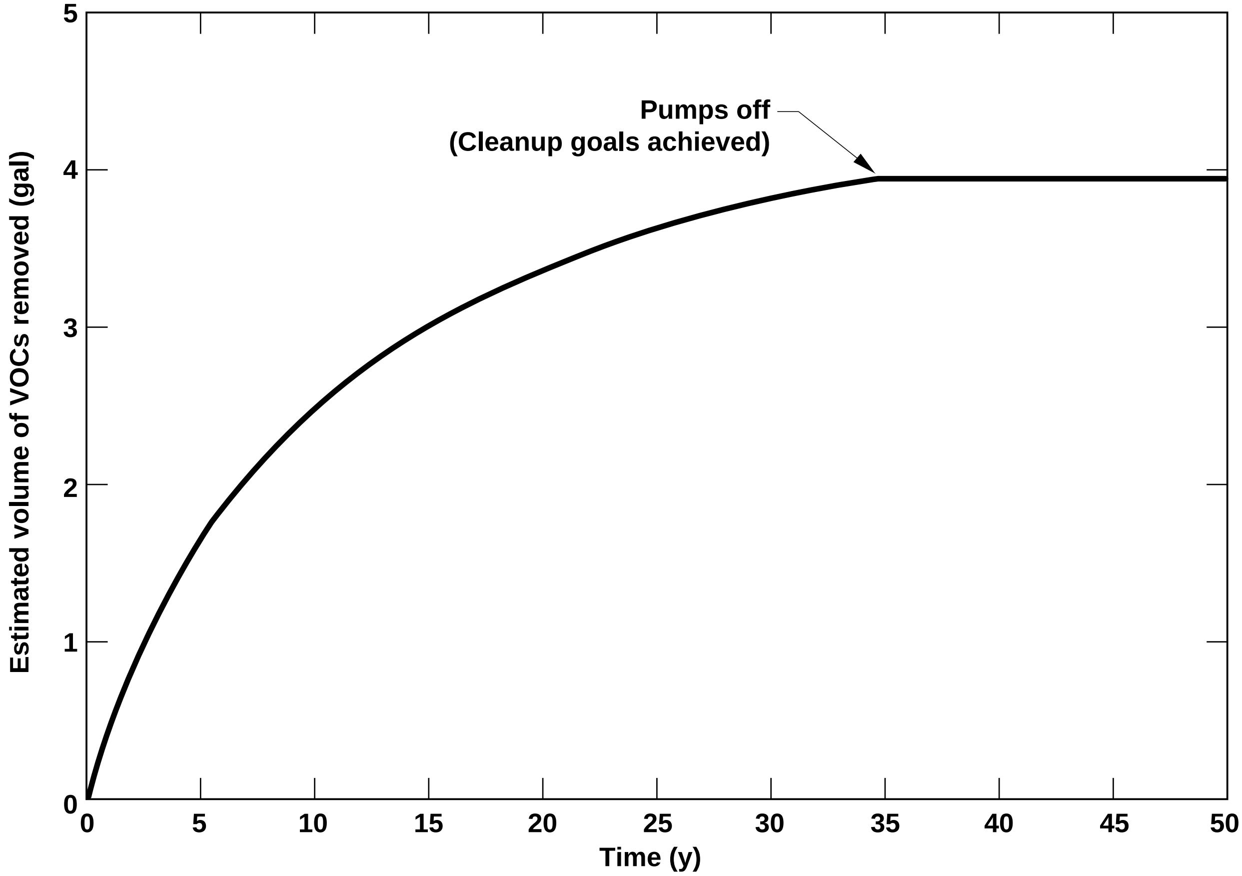

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Figure 8. Estimated cumulative volume of VOCs that may be removed from ground water by TFF over time.

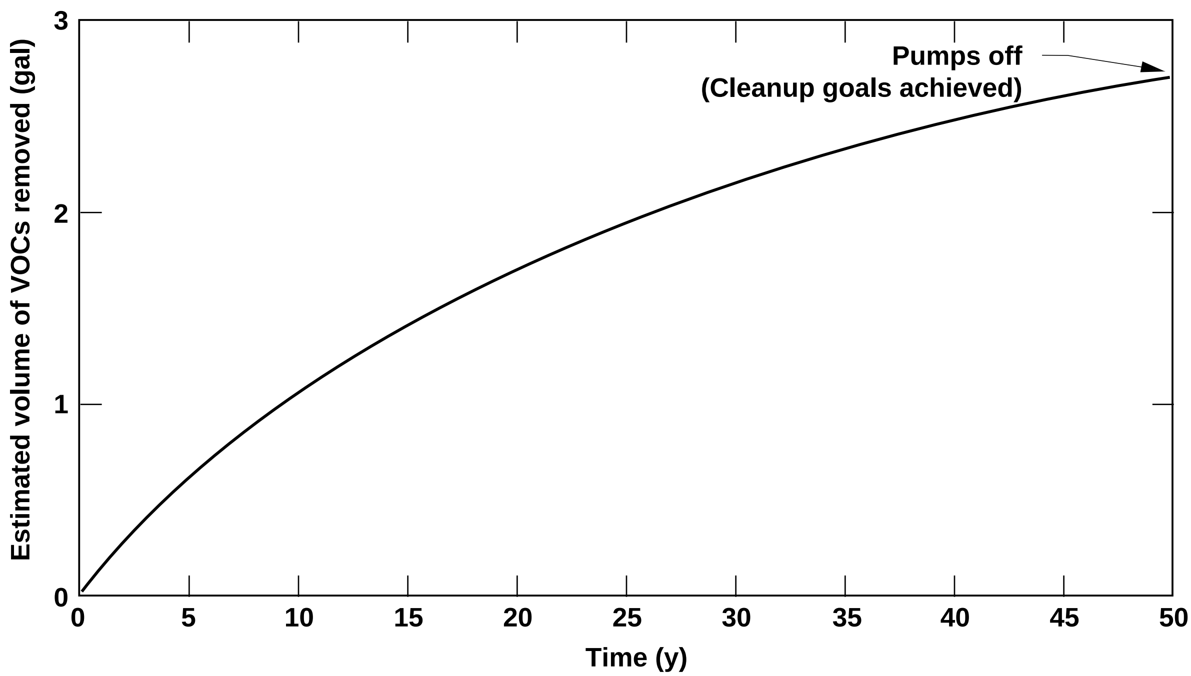

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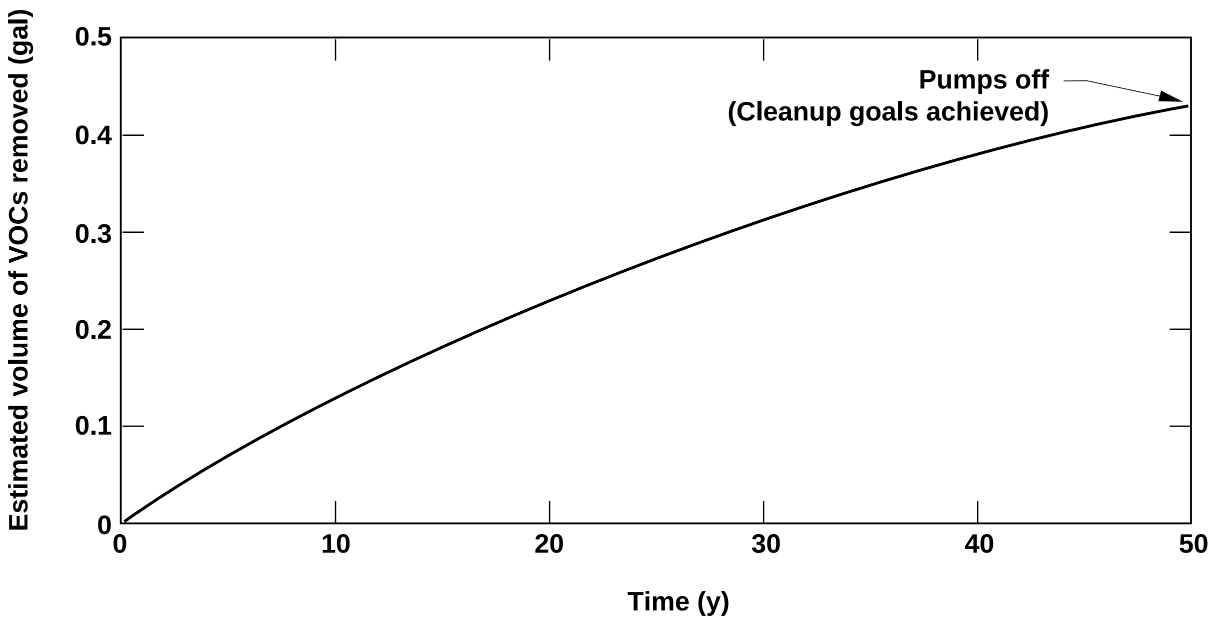
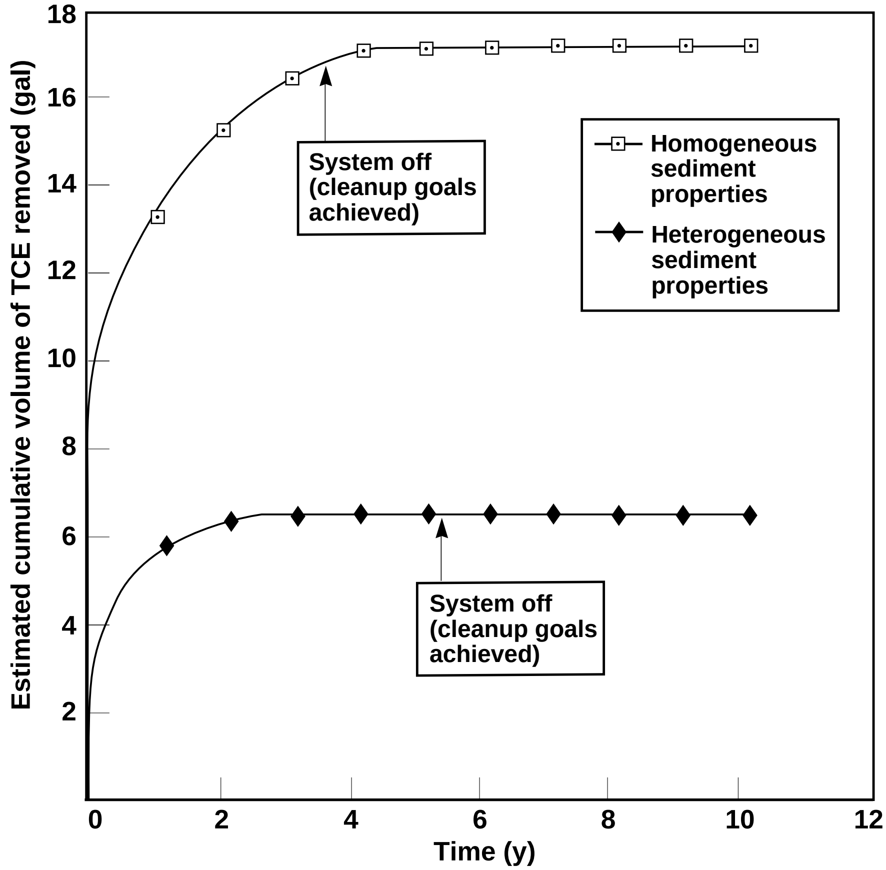
Figure 9. Estimated cumulative volume of VOCs that may be removed from ground water by TFG-1 over time.



CMP-95-Fig10

Figure 10. Estimated cumulative volume of VOCs that may be removed from ground water by TFG-2 over time.



CMP-95-Fig11

Figure 11. Estimated cumulative volume of TCE that may be removed by vapor extraction from the B-518 vadose zone over time at a vacuum pressure of 14 in. of Hg.

2. Objectives and Implementation

The procedures to evaluate Livermore Site remediation objectives are summarized below, and the implementation of these procedures are addressed.

2.1. Objectives

This document describes monitoring activities, procedures for collecting and interpreting data, and periodic evaluation and reporting of remediation progress. DOE/LLNL plan to assess the changes in COC distribution as remediation proceeds and, if needed, will propose changes to the remediation plans.

This CMP specifies the methods by which DOE/LLNL will monitor, interpret, and assess the progress of remedial actions at the Livermore Site to:

- Examine to what extent the ROD goals have been achieved.
- Evaluate the effectiveness of existing remedial actions.
- Evaluate scheduled and other proposed changes to ongoing remedial actions.
- Determine when specific cleanup actions should cease by comparing site data against applicable, relevant, or appropriate requirements (ARARs).
- Indicate and analyze deviations from expected performance.

An outline of this CMP was created based on guidance documents provided by the U.S. EPA (U.S. EPA, 1992a; 1992b; 1993; 1994), and concepts discussed in Gorelick *et al.* (1994), Hoffman (1993), and Keely (1989). This outline was submitted for regulatory agency review prior to preparing the draft document.

Because the remedial activities at the Livermore Site are expected to operate for many years, the project will stay current on advances in related areas, e.g., remote sensing, water level measurements, chemical analysis, databases, geographic information systems, fate and transport modeling, geophysical methods, etc. Proven advances in these areas will be incorporated into the remediation when justified, with concurrence from the regulatory agencies.

2.2. Implementation

This CMP outlines the procedures necessary to achieve the remediation objectives established in the ROD. The data collection (Section 3) and interpretation procedures (Section 6) described in this document are those already in use by the project, and are planned to continue to be used over the cleanup period.

3. Data Collection

Data on chemical, hydraulic, and subsurface material properties are required to track the progress of remedial actions and to monitor the site after active remediation ceases. Each data category is described below.

3.1. Chemical Data

To track remediation progress, chemical data on ground water, soil vapor, and treatment facilities are collected and analyzed as discussed in Sections 3.1.1 and 3.1.2. All work performed at LLNL follow the policies set forth in the Site Safety Plan (Bainer and Duarte, 1993).

3.1.1. Ground Water Extraction Wells, Monitor Wells, and Piezometers

Chemical concentrations in ground water will be measured by analyzing water samples collected from monitor wells, piezometers and extraction wells following the SOPs (Rice *et al*., 1990; Dibley, in preparation). A list of current SOP titles is presented in Appendix A. Chemical analyses will be performed according to established EPA Methods, and results will be evaluated according to the Livermore Site Quality Assurance/Quality Control (QA/QC) procedures in the Quality Assurance Project Plan (QAPP) (Rice, 1989).

Ground water concentrations at extraction, monitor wells and piezometers will be measured at a sampling frequency that is dependent in part on (1) the rate of observed or expected changes in concentrations in each well and other nearby wells (determined by using the algorithm presented in Appendix C), and (2) the location of the well relative to the downgradient offsite plume margin, and nearby activities such as a pumping test or activation of a new extraction well. The algorithm (Appendix C) suggests a sampling frequency based on concentration changes in a well. The Facility Task Leader (FTL) can change the sampling frequency based on well location with respect to a plume or local activities. Thus, the FTL uses the algorithm as a tool for making informed and appropriate decisions concerning sampling frequency for the wells in their task area. DOE/LLNL will subsequently notify the regulatory agencies and solicit their input on sampling frequency changes.

Ground water concentrations will be determined by sampling extraction, monitor wells and piezometers to track changes in plume concentration and size that result from remediation and natural processes such as dispersion, diffusion and advection. Pumping and sampling locations and sampling frequency will be determined using isoconcentration and hydraulic capture zone maps, and interpolations and extrapolations of the evolving plume in space and time. Measured ground water concentrations will be used to prepare COC isoconcentration contour maps, which will be prepared annually, or as needed, and compared with ground water concentrations estimated from flow and transport model calculations beginning with the 1996 annual report. These comparisons enhance our understanding of the response of COC concentrations to ground water extraction so that calibrated interpolations and extrapolations can then be used to manage the extraction wellfield to produce the most cost-effective and expeditious remediation achievable with available funding.

Based on data from the remediation efforts to date, significant changes in ground water COC concentrations in the alluvial sediments at the Livermore Site (i.e., concentration changes discernible from analytical and/or sampling variability and uncertainty) are expected to occur over time intervals of months to years. Thus, quarterly sampling will be sufficient at locations where changes are occurring. Where concentration changes are slow or nonexistent, samples will be collected less frequently (i.e., semiannually, annually, or biannually). Sampling frequencies greater than quarterly may be necessary where very rapid concentration changes are anticipated or observed. Such concentration changes may indicate that COC sources, distribution, and/or transport pathways may not have been sufficiently characterized.

Currently all monitor wells are used to characterize and track the onsite and offsite plumes. Appendix B indicates well locations (Fig. B-1) and lists all monitor wells grouped by HSU. “Guard” wells (selected wells primarily downgradient from the plume perimeter, Table 2 and Fig. B-1) will be monitored quarterly to verify horizontal and vertical plume containment. These guard wells may be redesignated as cleanup progresses and the plume front retreats. The algorithm in Appendix C will be used to suggest sampling frequency for the remaining wells not listed on Table 2. However, the suggested sampling frequency of these wells may be changed by the FTL, as discussed in Appendix C. Monitoring may also be discontinued in a well if two or more wells monitor similar portions of the plume.

Table 2. Offsite guard wells.

Well	Hydrostratigraphic unit	Location
W-104	1A	TFC
W-251	1A	TFA, TFB
W-558	1B	TFA, TFG
W-651	1B	TFA
W-481	1B	TFB
W-421	1B	TFC
W-517	1B	TFC
W-121	2	TFA
W-405	2	TFA
W-151	2	TFA, TFB
W-322	2	TFA, TFG
W-323	2	TFB, TFC
W-263	2	TFG
W-407	3A	TFA
W-410	3A	TFA
W-315	3A	TFD
GSW-009	3B	TFF
W-618	3B	TFE
W-913	4	Site Boundary
W-110	5	Site Boundary

3.1.2. Soil Vapor Extraction and Monitoring Points

Soil vapor VOC concentrations measured before, during, and after remedial action will be used to evaluate the performance of vadose zone extraction and treatment systems. Based on treatability test data and experience at other sites, COC concentrations in soil vapor are anticipated to change over time intervals of weeks under stressed conditions (i.e., during soil vapor extraction), or months to years under natural conditions.

Soil vapor samples will be collected from each vapor extraction well and appropriate soil vapor monitoring points. VOC concentrations will be measured (1) with a flame ionization detector (FID), which provides approximate concentrations of organic constituents, and (2) by laboratory analysis, which provides quantification of individual constituents.

Field FID readings will be calibrated to a gas standard in the field. The field reading will be compared to a lab analysis to assess the accuracy of the field measurements once per week for the first month of operation. Calibration of the FID is described in SOP 4.8, and analytical quality control is addressed in SOP 4.2 (Rice *et al*., 1990; Dibley, in preparation). A lab comparison sample will be analyzed at a minimum of once a month after the initial month of operation, unless very rapid concentration changes are anticipated or observed.

VOC concentration data will be used to maximize system effectiveness (e.g., plume containment, mass removal, and reductions of *in situ* COC concentrations) by determining the contribution of mass from each well to the total influent. After system startup, samples will be collected weekly for the first 6 weeks of operation. After 6 weeks, the soil vapor monitoring frequency algorithm, presented in Appendix D, will be used to determine if sampling frequency reductions are feasible. The FTL will review the results of the algorithm for each soil vapor extraction and monitoring location to determine if the sampling frequency should change.

3.1.3. Treatment System Influent and Effluent

Influent and effluent concentrations at each treatment facility will be measured to monitor the treatment facility effectiveness and efficiency, and to meet discharge permit requirements. The influent media will be ground water or soil vapor; the treated effluent media will be water, soil vapor, and/or air stripper offgas. At each treatment facility, influent ground water samples will be collected monthly from the combined flow from all active extraction wells to evaluate remediation effectiveness. As stipulated by the self-monitoring requirements of each treatment facility, effluent sampling in combination with influent ground water samples will be used to evaluate the performance of each facility.

3.2. Fluid Data

Fluid data collection includes monitoring water levels, soil vapor pressures, and extraction flow volumes.

3.2.1. Water Levels

Hydraulic head (water level) measurements will be collected monthly at all monitor, extraction, and injection wells and all piezometers to define flow direction, the extent of hydraulic influence, and capture zones for extraction wells. Hydraulic heads can significantly change over time intervals of seconds (e.g., in response to abrupt changes in pumping or injection rates) to months (e.g., as a result of seasonal variations in recharge and evapotranspiration). Therefore, water level measurements may be collected more frequently during pump tests and/or facility startup or shutdown. If necessary, additional measurements will be collected if the configuration of the extraction system is altered (e.g., if a well is turned off or when flow rates are adjusted) to assess whether hydraulic capture and plume containment objectives are being achieved. Ground water elevation contour maps showing inferred extraction well capture zones will be prepared quarterly, or as needed (Fig. 12). Where there is little or no change in pumping rates and locations, the water levels and capture zones are anticipated to remain fairly stable. When water levels are stable, water level measurements will be collected less frequently with regulatory concurrence, and water level contour maps showing inferred capture zones will be prepared annually for those areas.

3.2.2. Soil Vapor Pressures

Soil vapor pressure will be measured at extraction wells and appropriate soil vapor monitoring points to define flow direction and calculate flow velocity, the extent of pressure influence, and capture volumes. Pressure measurements will be made monthly during system operation, and may be made more frequently during facility startup or shutdown. Additional measurements will be made as necessary if the configuration of the extraction system is altered (e.g., if a well is turned off or when flow rates are adjusted) to assess whether the vapor extraction objectives are being achieved.

3.2.3. Extraction Flow Quantities

Water and soil vapor flow volume measurements will be collected monthly from each extraction and injection well using flow rate meters and/or totalizing meters. Measuring the water or soil vapor volume from each extraction and injection well is necessary to estimate COC removal rates and to estimate the impact of each well on subsurface flow conditions.

3.3. Subsurface Material Properties

Hydraulic data (e.g., pumping rates, water levels, hydraulic conductivity, and moisture content), descriptive geologic data, and geophysical data are required to analyze and estimate hydraulic capture zones and COC concentration distributions, and to compare these estimates with the field-measured data. These data and hydraulic estimates then calibrate our understanding of the ground water flow and the COC concentrations in flow and transport models that are used to manage remediation performance and assess risk as the cleanup proceeds.

Collection of pumping rate and water level data is described above in Sections 3.2.1 and 3.2.3. Hydraulic conductivity values are calculated from pumping tests, and occasionally from lab tests on soil cores. These data will be collected as needed as determined by the FTL and DOE/LLNL hydrogeologists. Moisture content data are generated from lab tests. These data are collected when needed for vadose zone analysis and modeling. Geologic data (lithologic descriptions on well logs) will continue to be collected from all monitor well, extraction well, piezometer and source investigation boreholes. Geophysical data (resistivity, spontaneous potential, gamma, and/or induction logs) will be collected from boreholes specified by DOE/LLNL hydrogeologists.

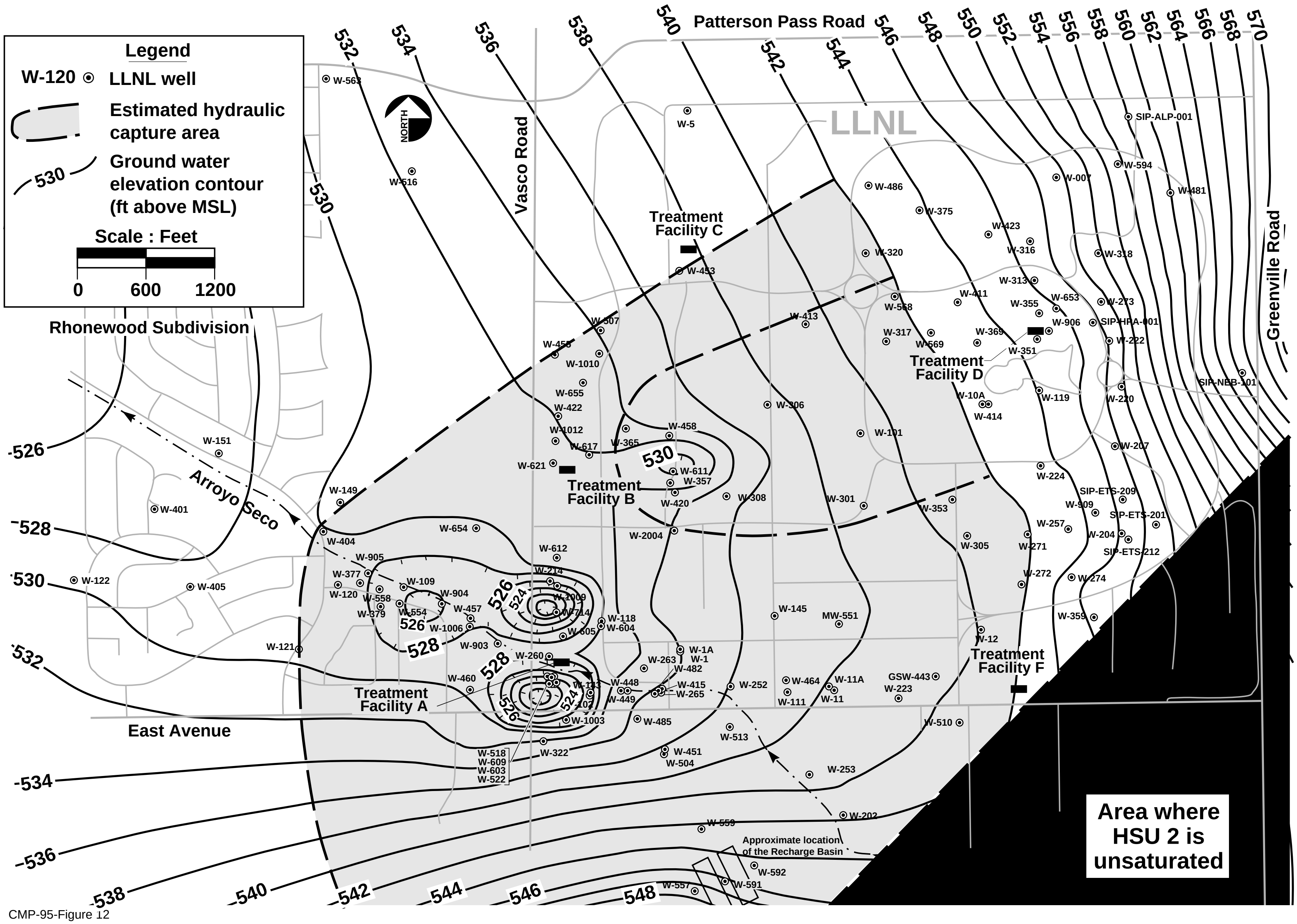


Figure 12. Ground water elevation contour map for 135 wells completed within HSU 2 and estimated HSU 2 hydraulic capture areas, LLNL and vicinity, September 1995. (Since TFD extraction wells were not pumping during the third quarter, no hydraulic capture area is shown at TFD.)

4. Data Management

Compliance monitoring data will be managed using current systems and procedures as described below.

4.1. Database Structure and Organization

Compliance monitoring data will be archived in the Environmental Protection Department (EPD) electronic database. The EPD database, called EPD Data, is a single relational database that contains CERCLA ERD data. DOE/LLNL also plan to include gallons pumped by each extraction well in the database. Currently, the database also contains data from non-CERCLA environmental monitoring, preconstruction soil sampling, tank characterization, and other terrestrial and atmospheric monitoring.

EPD Data includes SPACT (the sampling plan and tracking tables) and Monitor (the integrated environmental tables). Site characterization, source investigation, risk assessment, and compliance monitoring have necessitated collecting tens of thousands of environmental samples, and hundreds of thousands of analytical results. Sample collection and tracking are managed in SPACT, and the resulting analytical data are managed within Monitor.

The ERD electronic database is currently maintained on a VAX 6310 system using Ingres relational database management software. However, the system will evolve as new technology and software become available and project needs change. A bimonthly view of EPD Data is made available as a read-only date-stamped database (Gemini) and archived for future reference. When retrievals are made from the Gemini database, the date-stamp is recorded with the retrieval.

4.2. Data Storage and Retrieval

Data-naming conventions are specified in the ERD SOPs (Rice *et al.*, 1990; Dibley, in preparation), and are used to identify data types, date collected, and other pertinent information. Each sample entry in the database includes relational information (location and date) to facilitate acquisition of related data sets. This information increases the utility of the acquired data by providing readily accessible data sets. These data sets can be used to track trends, compare chemical and hydrogeological data from separate areas of the site, and monitor remediation performance.

Most data received by the ERD Data Management Group (DMG) are stored in the relational database. However, some nondiscrete data types, such as flow data recorded by data loggers, are stored electronically, but not as part of the relational data base. A few data types, such as the full record produced during geophysical logging, hydraulic testing, or some forms of sample documentation, are not readily recorded in electronic form, and are stored in hard copy in the ERD Data Reference Library.

Data are received into the database electronically or hand entered by DMG personnel. Standard verification checks are run on all entries, and all hand entered data are cross checked. All data are flagged with a status indicator that specifies the validation status (e.g., validated using EPA functional guidelines, historical comparison only, or not validated). Data qualifier flags assigned during the validation and review process are also stored electronically. If data that have been entered correctly are believed to be flawed, they are flagged, however, they are not altered. Time-trend statistical outliers are also flagged electronically. Data of known quality are thus available for future use. Data validation procedures are outlined in SOP 4.6 (Rice *et al.*, 1990; Dibley, in preparation). SOP titles are presented in Appendix A.

Data are delivered to users by standard reports, unique individual data requests, and movement of data into external analysis programs for statistical analysis or graphical interpretation. INGRES software utilities such as Report Writer and/or Structural Query Language are used for retrievals and extractions. ERD will allow regulatory agencies access to the Ground Water Project database.

5. QA/QC and Standard Operating Procedures

The Livermore Site Ground Water Project has been using a QAPP (Rice, 1989) and a Quality Assurance Plan (QAP) (ERD, 1994) that establish and present the framework and requirements for planning, performing, documenting, and verifying work and related data for the Livermore Site remediation. The QAPP was prepared for CERCLA compliance and ensures that the precision, accuracy, completeness and representativeness of project data are of acceptable quality. The QAPP was prepared according to EPA guidance and was approved by the regulatory agencies. The QAP is a quality assurance document prepared for DOE and follows the standards of the American Society of Mechanical Engineers Nuclear Quality Assurance-1 (ASME NQA-1), "Quality Assurance Program Requirements for Nuclear Facilities" and fulfills the requirements of the EPA Quality Assurance Management Staff (QAMS) 005/80, "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans." The QAPP and QAP are intended to be used in conjunction with ERD SOPs and workplans. SOPs have been established for all aspects of well drilling and logging, soil and water sampling, and hydraulic testing. The existing QAPP, QAP, and SOPs are applicable to all pertinent monitoring and reporting activities since the ROD.

6. Data Analysis

Several remediation performance measures can be developed using existing data. Each is a useful performance measure, however, none should be used as the sole performance measure. The remediation performance measures that DOE/LLNL plan to use at the Livermore Site are discussed below.

Many of the interpretive methods necessary to assess the progress of remediation in the subsurface require a basic subsurface conceptual model. Such a model can be represented partly by hydrogeologic cross sections and other interpretive renderings such as two- and three-dimensional visualizations of the hydrogeology and COC distribution. These visualizations are instrumental in understanding and communicating the progress of remediation to regulators and the community. At the Livermore Site, such interpretations are based on the subsurface conceptual model of the HSU (Berg *et al.*, 1994a). For example, COC distributions and hydraulic head are interpreted within each HSU. As remediation proceeds, we plan to continue building on this framework to understand how the cleanup is progressing. Descriptions of each HSU, including how it was defined, its spatial extent, and general hydrogeologic characteristics, will be addressed as remediation continues. Interested parties are welcome to schedule meetings with DOE/LLNL to observe the HSU and modeling work-in-progress.

6.1. Volume of Subsurface Material Affected by Remedial Activities

The three-dimensional region of hydraulic capture around extraction wells will be estimated using the hydraulic head distribution as determined by water level measurements. When assessing whether COCs are being contained by pumping, it is necessary to incorporate the three-dimensional effects of the heterogeneous subsurface to determine vertical and horizontal flow and COC migration behavior. For example, hydraulic head measurements will be analyzed to determine whether containment has been achieved vertically as well as horizontally. Hydraulic head (or soil vapor pressure) measurements represent three-dimensional gradient fields, so care will be taken when interpreting the field measurements to separate horizontal and vertical components. For example, only data from measuring points that are within a hydraulically distinct zone (hydrostratigraphic unit) will be used to interpret hydraulic heads within that unit. Figure 13 presents an example of hydraulic head and the estimated capture zone within a single HSU.

Many water level measuring points are required to estimate three-dimensional hydraulic capture with a high degree of confidence. It is unlikely that there will be sufficient water level measurement points to thoroughly define hydraulic capture in three dimensions in all areas. Other direct or remote sensing techniques will be used to supplement water level data if such methods are shown to be effective. Computer interpolations and extrapolations, applied in conjunction with field monitoring data, will then be used to estimate plume capture. This process will be accomplished by comparing three-dimensional flow and transport simulations and visualizations (or a series of two-dimensional simulations based on HSUs as shown in Fig. 14) of COC distributions and changes in COC distribution, with inferred or simulated ground water flowlines.

Analyzing hydraulic head data, and monitor wells near plume margins will help ensure plume containment in targeted regions, and will identify stagnation zones where remedial efforts are less effective. Identification of such zones will result in changes in pumping rates and/or locations to ensure complete remediation.

6.2. Estimating COC Distribution and Mass in Subsurface Material

The three-dimensional COC distribution in the subsurface is estimated by interpolating site-specific chemical data, such as VOC concentrations in ground water. Estimates of the COC mass removed are based on both the volume and COC concentration of extracted ground water and soil vapor. The COC mass remaining in the subsurface will be estimated by comparing the cumulative mass removed to (1) original mass estimates presented in the RD and FS reports, and (2) subsequent mass estimates based on modeling of COC distribution.

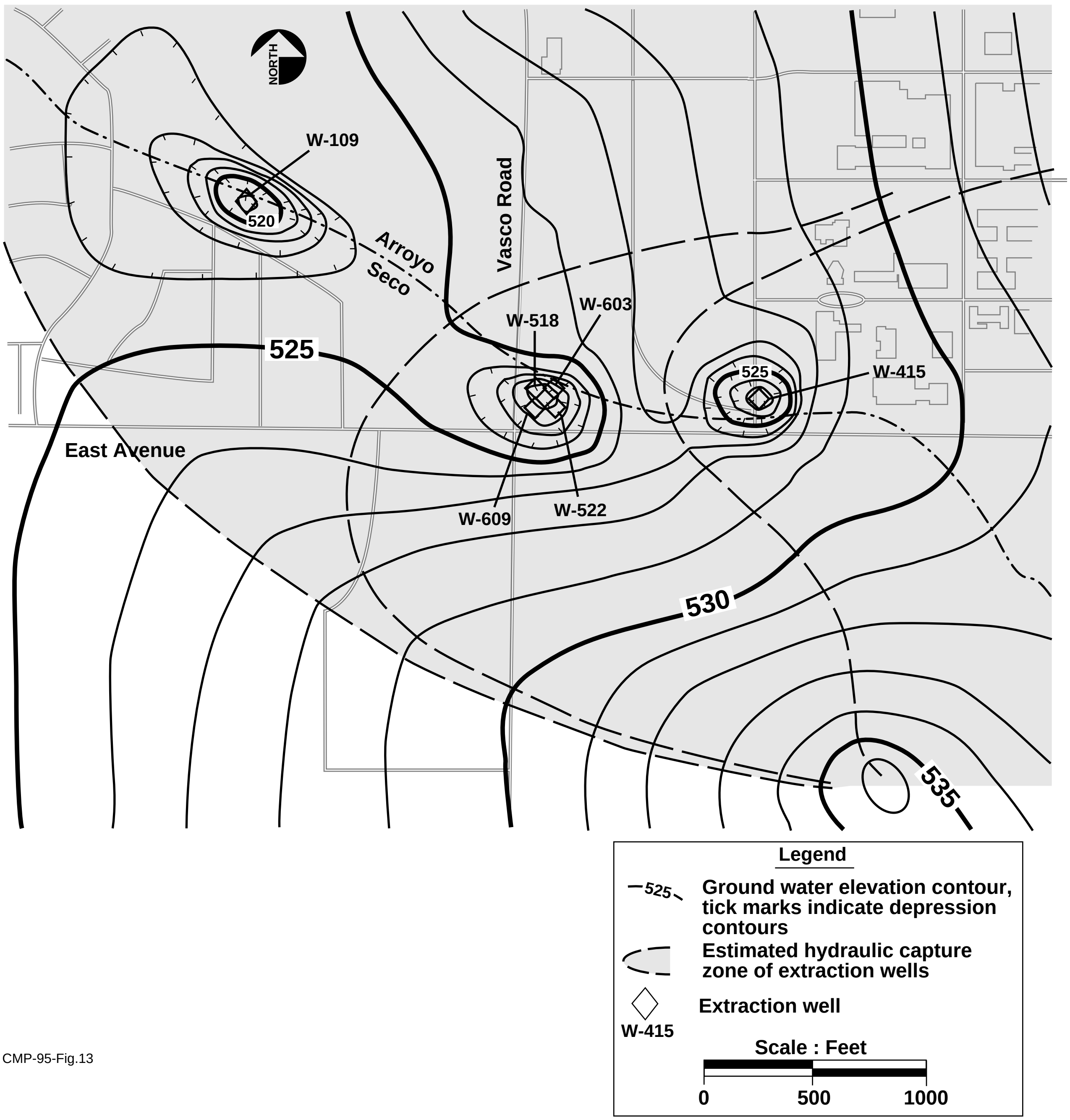
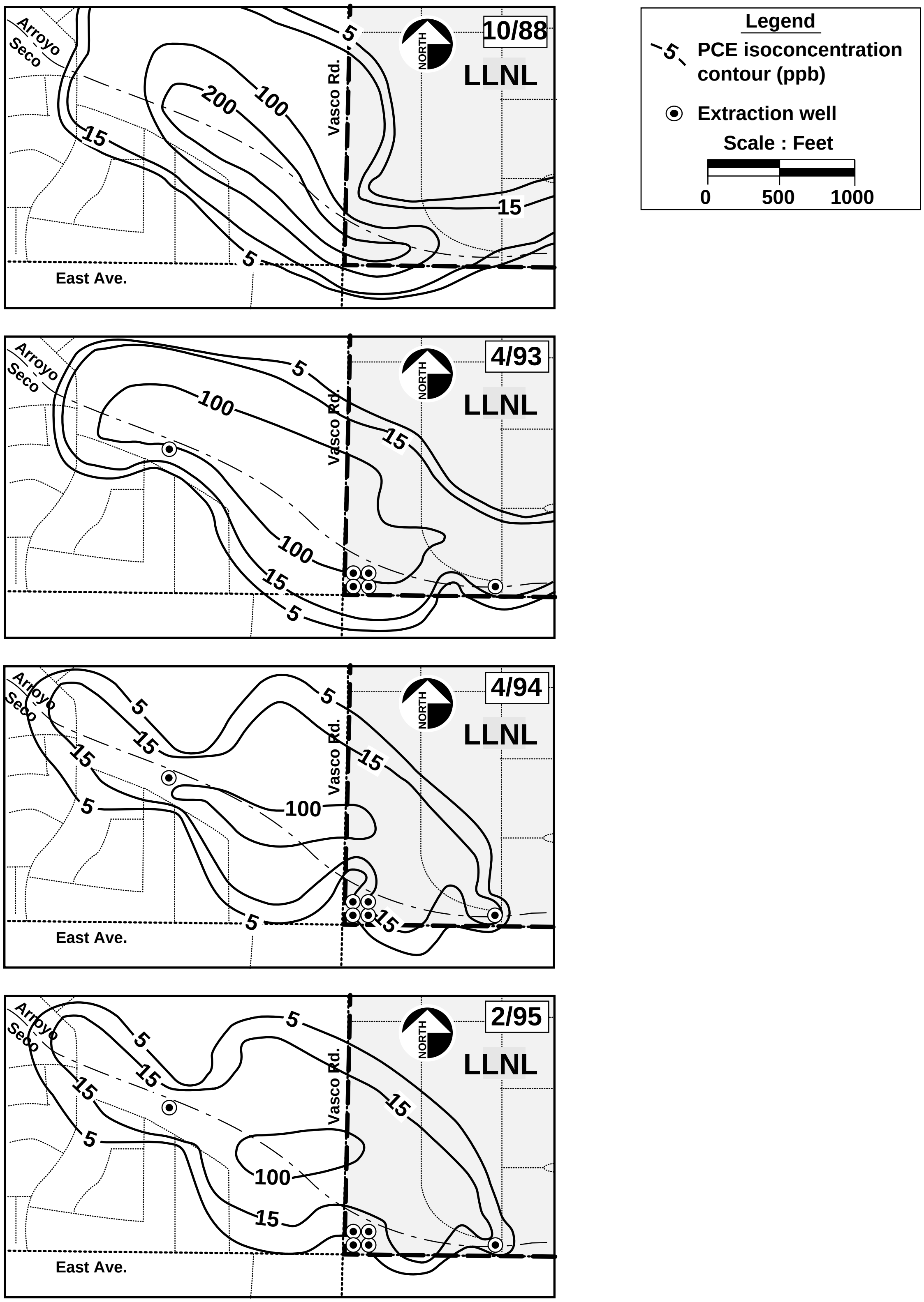


Figure 13. Ground water elevation contour map showing distribution of hydraulic head and estimated capture zone within HSU 2 (TFA Area).



CMP-95-Fig.14

Figure 14. Isoconcentration contour maps showing the change in PCE distribution over time within HSU 2 (TFA Area).

Estimates of the COC mass remaining in the subsurface will be used to revise cleanup time estimates and re-evaluate wellfield configurations. Visualizations of COC mass distribution are necessary and important tools to understand and communicate progress of the cleanup. As discussed below, available data may limit the accuracy of COC mass estimates; therefore, mass removal and flow rates from extraction wells will also be used to assess treatment facility effectiveness.

6.2.1. Distribution

The subsurface COC spatial distribution can be estimated from available ground water, soil, and soil vapor concentrations using interpolation and extrapolation techniques. Various interpolation methods will be employed to estimate the spatial distribution of field data and create isoconcentration contour maps, hydraulic head contour maps, and various other two- and three-dimensional visualizations of geologic, chemical, and hydraulic data. Whatever method is used, the impact that the particular interpolation method has on resulting interpretations will be evaluated.

Future estimates of the subsurface COC distribution may or may not be as accurate as the initial estimate. The initial estimate was based on an interpolation algorithm developed by LLNL (Devany *et al.*, 1990) that combined soil, soil vapor, and ground water concentrations, and qualitative geologic data to obtain a more detailed and better-constrained interpolation of the COC distribution between repeatable measurement locations (i.e., monitor wells). However, this technique depends on the availability of a significant number of representative saturated soil COC concentrations from soil samples collected during drilling.

The subsurface sediment has been sampled at more locations than has ground water, so much of the knowledge of the current distribution and mass of the ground water plume is inferred from soil samples. Water and soil vapor samples from wells are repeatable measurements, whereas soil samples from boreholes are not. In addition, previous saturated and unsaturated soil analyses will become less representative of current and future conditions as remediation continues. As a result, the pre-remediation COC distribution will, in many locations, be more thoroughly characterized than at any time after remediation has begun.

6.2.2. Mass

COC mass removal will continue to be estimated by integrating concentrations and volumes of extracted ground water or soil vapor over time. This estimate will be relatively accurate if all significant changes in influent concentrations from each extraction well and monthly extraction volumes are recorded. To gather such data, flow meters will be installed for each extraction well, and the sampling frequency may be adjusted to adapt to trends in measured concentrations in extracted ground water or soil vapor. Changes in ground water and soil vapor chemical concentrations through time will be evaluated during the remediation process, and will be used to interpret the effectiveness of remedial actions.

For each CERCLA 5-year review, the total estimated COC mass removed will be compared to the difference between (1) original mass estimates presented in the RD reports (Figs. 3 through 11) and the FS (Isherwood *et al.*, 1990), and (2) subsequent mass estimates based on future COC distribution. The mass estimates will be used to evaluate the accuracy of previous mass estimates and to refine estimates of COC mass removal rates and cleanup times.

Mass removal and flow rates from extraction wells will be used to assess the overall effectiveness of each extraction system. Effectiveness will be judged by how well the system is reducing COCs below ARARs and how well it is controlling offsite plume migration. If necessary, additional extraction wells may be installed to increase COC mass removal rates and/or to improve hydraulic containment of the plume. A separate, subordinate measure of facility performance is the treatment efficiency, which is the measure of concentration reduction achieved in the ground water or soil vapor treated by the facility.

6.3. Re-evaluating Remediation Plans

The data collected and interpretations developed during compliance monitoring will be used to update conceptual and computational models of the Livermore Site subsurface. This updated and improved understanding will be used to periodically re-evaluate and improve upon the remediation plans, determine when project goals have been achieved, and determine when active remediation should cease (U.S. EPA, 1992a,b,c). When models suggest changes to remediation plans, DOE/LLNL will involve the regulatory agencies in evaluating the suggested changes. Changes to remediation plans will be made only with regulatory concurrence. As will be discussed in the forthcoming Contingency Plan, Non-Attainment Zone (Morse *et al.*, 1995) (currently referred to as Containment Zone) or Technical Impracticability (U.S. EPA, 1993) concepts may be applied with regulatory approval to some or all of the site after sufficient remediation has occurred.

Post-closure monitoring and project activities in the post-closure period are addressed below.

6.3.1. Ground Water

As described in RD Reports Nos. 1, 2, 3, and 5 (Boegel *et al.*, 1993; Berg *et al.*, 1993; Berg *et al.*, 1994a; Berg *et al.*, 1995), COC concentrations will be monitored for 2 years after pumping ceases. At some LLNL extraction wells (i.e., those in former source areas with VOCs in the shallowest ground water) pumps may be periodically shut off and the water levels allowed to recover. During pump-off cycles, VOCs should desorb into the ground water from the sediments that were dewatered near the pumping wells. Cycling the pumps may increase VOC removal rates near former source areas, where most of the VOCs occur in the shallower water-bearing sediments. Different pump-on and pump-off cycles may be evaluated to determine the optimum periods of pumping and non-pumping to maximize VOC mass removal rates.

Once VOCs remain below negotiated ARARs and extraction wells are shut off, monitor wells will be sampled quarterly for the first year, and semiannually for the second year. If concentrations rise above negotiated ARARs, extraction will resume at the appropriate wells until negotiated ARARs are again achieved. Cleanup will be considered complete when COC concentrations remain below the remediation standards for 2 years. It is likely that remedial objectives will be achieved in some areas prior to others, and that remediation will then cease in some areas prior to others. After concurrence with the regulatory agencies that cleanup is complete, all treatment system hardware will be decontaminated, dismantled, and salvaged, and most of the LLNL extraction wells and piezometers will be sealed and abandoned.

6.3.2. Soil Vapor

Vapor flow rates and chemistry data will be collected to evaluate the effectiveness of the vapor extraction systems. Some vapor extraction wells may be periodically shut off to determine if the vapor concentrations increase. As specified in RD Report No. 6 (Berg *et al.*, 1994b), data from ongoing field monitoring and periodic model recalibration will be used to estimate when vadose zone cleanup will be complete. Sediment and/or soil vapor samples will be collected to confirm that cleanup objectives have been met. When the vadose zone cleanup is complete, as determined in conjunction with the regulatory agencies, all treatment system hardware will be decontaminated, dismantled, and salvaged. Vapor extraction wells will be sealed and abandoned.

7. Reporting

The progress of remediation will be reported during regularly scheduled Remedial Program Manager's (RPM) meetings. The format and frequency of such meetings will be determined by the participating agencies. Items to be presented may include (1) reports on the progress of cleanup and the status of compliance (using isoconcentration and capture zone maps, cross sections, tables, and graphs), (2) comparisons of predicted and measured performance, (3) updates to the conceptual and computational models (in response to new field data and/or interpretations) to improve future remediation decisions, (4) source investigation results, and (5) any proposed changes to the remediation plans that may result from advances in new viable technologies, ongoing source investigations, changes in regulatory policies, etc. Any changes to Livermore Site remediation plans will be implemented with regulatory approval.

Ground water levels and COC concentrations are expected to change more rapidly during the early stages of remediation, followed by periods of less rapid or significant change. Therefore, ground water elevation contour maps showing estimated hydraulic capture zones, and estimates of COC mass removed from the subsurface, will be reported quarterly as the ground water extraction systems are installed and begin operating. After all treatment facilities are operating and a relatively steady ground water flow field is established, water level contour maps and COC mass removal estimates will be reported annually, with regulatory approval.

Similarly, during the initial phase of ground water remediation, isoconcentration contour maps will be presented annually. As the remedial process matures and the COC distribution in ground water is not changing appreciably, COC isoconcentration contour maps may be presented at each CERCLA 5-year review, with regulatory approval. However, to ensure effective cleanup of the subsurface, ground water levels and COC concentrations will be monitored more frequently than the reporting described above. Reporting requirements are presented in Appendix E.

8. Budget

DOE/LLNL will provide updates and inform the regulatory agencies of any change to the budget that affects cleanup at the RPM meetings. If budget changes adversely affect cleanup, remediation tasks will be conducted according to the priorities established in the *RPM Consensus*

Statement for Environmental Restoration of LLNL Main Site dated July 20, 1994. DOE/LLNL and the regulatory agencies will meet at least annually to discuss budget issues and their implications on enforceable milestones.

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Appendix A

Standard Operating Procedure Titles

Appendix A

Standard Operating Procedure Titles

A-1. Titles

The titles of the LLNL ERD SOPs are listed below. All existing SOPs are currently being updated, and as noted below, additional SOPs are being written.

SOP 1.1	Field Borehole Logging
SOP 1.2	Borehole Sampling of Unconsolidated Sediments and Rock
SOP 1.3	Drilling
SOP 1.4	Monitor Well Installation
SOP 1.5	Monitor Well Development
SOP 1.6	Borehole Geophysical Logging
SOP 1.7	Well Closures
SOP 1.8	Disposal of Investigation-Derived Wastes (Drill Cuttings, Core Samples, and Drilling Mud)
SOP 1.9	Lysimeter Soil Moisture Sampling
SOP 1.10	Soil Vapor Surveys
SOP 1.11	Soil Surface Flux Monitoring of Gaseous Emission
SOP 1.12	Surface Soil Sampling
SOP 1.13	SIMCO Drill Rig Operation
SOP[a]	Core Logging (New)
SOP 2.1	Presample Purging of Wells
SOP 2.2	Field Measurements on Surface and Ground Waters
SOP 2.3	Sampling Monitor Wells with Bladder and Electric Submersible Pumps
SOP 2.4	Sampling Monitor Wells with a Bailer
SOP 2.5	Surface Water Sampling
SOP 2.6	Sampling for Volatile Organic Compounds
SOP 2.7	Presample Purging and Sampling of Low Yielding Monitor Wells
SOP 2.8	Installation of Dedicated Sampling Pumps

SOP 2.9	Sampling for Tritium in Ground Water
SOP 2.10	Chlorination of Monitor Wells Prior to Bacteria Sampling
SOP 2.11	Developing Ground Water Monitoring Sampling Schedules
SOP 2.12	Ground Water Monitor Well and Equipment Maintenance (New)
SOP[a]	Sampling Wells using Low Volume Purge Techniques (New)
SOP 3.1	Water Level Measurement
SOP 3.2	Pressure Transducer Calibration
SOP 3.3	Hydraulic Testing (Slug/Bail)
SOP 3.4	Hydraulic Testing (Pumping)
SOP 4.1	General Instructions for Field Personnel
SOP 4.2	Sample Control and Documentation
SOP 4.3	Sample Containers and Preservation
SOP 4.4	Guide to the Handling, Packaging, and Shipping of Samples
SOP 4.5	General Equipment Decontamination
SOP 4.6	QA/QC Objectives for Non-Radiological Data Generated by Analytical Laboratories
SOP 4.7A	Livermore Site Treatment and Disposal of Well Development and Well Purge Fluids
SOP 4.7B	Site 300 Treatment and Disposal of Well Development and Well Purge Fluids
SOP 4.8	Calibration and Maintenance of Field Instruments Used in Measuring Parameters of Surface and Ground Water and Soils
SOP 4.9	Collection of Field QA/QC Samples
SOP 4.10	Photovac Portable Gas Chromatograph Operating Instructions
SOP[a]	Inspection and Testing (New)
SOP[a]	QA/QC Objectives for Radiological Data Generated by the Analytical Laboratories (New)
SOP 5.1	Data Management Printed Analytical Result Receipt and Processing
SOP 5.2	Data Management Chain of Custody Receipt and Processing
SOP 5.3	Data Management Electronic Analytical Result Receipt and Processing for Sample Analysis Data
SOP 5.4	Data Management Hand Entry of Analytical Results
SOP 5.5	Data Management Revision Receipt and Processing
SOP 5.6	Data Management Data Review Request Processing
SOP 5.7	Data Management Sample Location Entry

SOP 5.8	Data Management Controlled Field Log books Issue and Use
SOP 5.9	Data Management Processing of Invoices
SOP 5.10	Data Management Receipt and Processing of Lithology
SOP 5.11	Data Management Verification of Format and Quality of EDD
SOP 5.12	Data Management Update of Analysis DQFs
SOP 5.13	Data Management Receipt and Processing of QIFs
SOP 5.14	Data Management Validation of Analytical DQFs
SOP 5.15	Data Management Processing of Water Elevation Data Logger Data
SOP 5.16	Data Management Electronic Field COC Receipt and Processing
SOP 5.17	Data Management Reference Report Preparation and Distribution
SOP 5.18	EPDData Copy over Software Operating Procedure (New)
SOP[a]	Data Outliers (New)

[a] SOP number not determined at this time.

Appendix B

Livermore Site Monitor Wells

Appendix B

Livermore Site Monitor Wells

B-1. Wells by HSU

Listed below are wells monitored at the Livermore Site grouped by HSU. Well locations are shown on Figure B-1. Guard wells discussed in Section 3.1.1. are noted below and highlighted on Figure B-1.

HSU 1A

W-104[a] W-108 W-123 W-203 W-251[a] W-552

HSU 1B

W-002 W-004 W-005 W-101 W-103 W-105 W-114 W-115 W-116 W-141 W-147 W-148 W-213 W-218 W-226 W-254 W-262 W-269 W-302 W-307 W-368 W-373 W-402 W-406 W-408 W-409 W-412 W-415 W-416 W-417 W-419 W-421[a] W-452 W-454 W-459 W-463 W-481[a] W-501 W-502 W-503 W-506 W-514 W-515 W-517[a] W-519 W-520 W-521 W-555 W-556 W-558[a] W-564 W-565 W-567 W-571 W-601 W-602 W-604 W-606 W-607 W-608 W-610 W-611 W-613 W-614 W-615 W-620 W-651[a] W-701 W-702 W-704 W-705 W-706 W-901 W-902 W-1001 W-1004 W-1005 W-1013 W-1014 W-1015 W-1101 W-1102 W-1103 W-1104 W-1105 W-1106 W-1107 W-1109 W-1110 W-1116

HSU 2

W-001 W-001A W-002A W-005A W-007 W-010A W-012 W-102 W-109 W-111 W-118 W-119 W-120 W-121[a] W-122 W-142 W-143 W-146 W-149 W-150 W-151[a] W-201 W-202 W-204 W-207 W-214 W-220 W-222 W-223 W-224 W-252 W-253 W-257 W-259 W-260 W-263[a] W-264 W-271 W-272 W-273 W-274 W-301 W-303 W-305 W-306 W-308 W-313 W-316 W-317 W-318 W-320 W-322[a] W-323[a] W-353 W-355 W-357 W-365 W-369 W-375 W-376 W-377 W-378 W-379 W-401 W-404 W-405[a] W-411 W-413 W-414 W-418 W-420 W-422 W-423 W-448 W-449 W-451 W-453 W-455 W-457 W-458 W-460 W-461 W-464 W-482 W-483 W-485 W-486 W-504 W-507 W-510 W-513 W-516 W-518 W-522 W-551 W-553 W-554 W-557 W-559 W-563 W-568 W-569 W-591 W-592 W-594

W-603 W-605 W-609 W-612 W-617 W-621 W-654 W-655 W-714 W-903 W-904 W-905 W-906 W-909 W-911 W-1003 W-1006 W-1009 W-1010 TW-11 TW-11A W-1112

HSU 3A

7D2 W-008 W-205 W-206 W-210 W-221 W-258 W-267 W-310 W-311 W-315[a] W-319 W-324 W-325 W-361 W-363 W-371 W-380 W-407[a] W-410[a] W-424 W-446 W-456 W-484 W-505 W-593 W-616 W-653 W-712 W-1007

HSU 3B

W-265 W-276 W-277 W-292 W-487 W-560 W-618[a]
GSW-009[a]

HSU 4

W-256 W-304 W-312 W-314 W-351 W-352 W-354 W-356 W-360 W-362 W-364 W-366 W-370 W-372 W-447 W-511 W-619 W-907 W-913[a]

HSU 5

W-011 W-017 W-106 W-107 W-110[a] W-112 W-113 W-212 W-217 W-219 W-225 W-255 W-261 W-268 W-270 W-275 W-290 W-291 W-293 W-294 W-321 W-359 W-441 W-450 W-462 W-509 W-512 W-561 W-562 W-566 W-622 W-703 W-750 W-912 W-1002 W-1108 W-1114

HSU 6

W-211 W-652 W-908

HSU 7

W-015 W-017A W-019 W-117 W-358 W-403 W-508 W-570

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[a] Guard well (see Table 2 in Section 3.1.1.).

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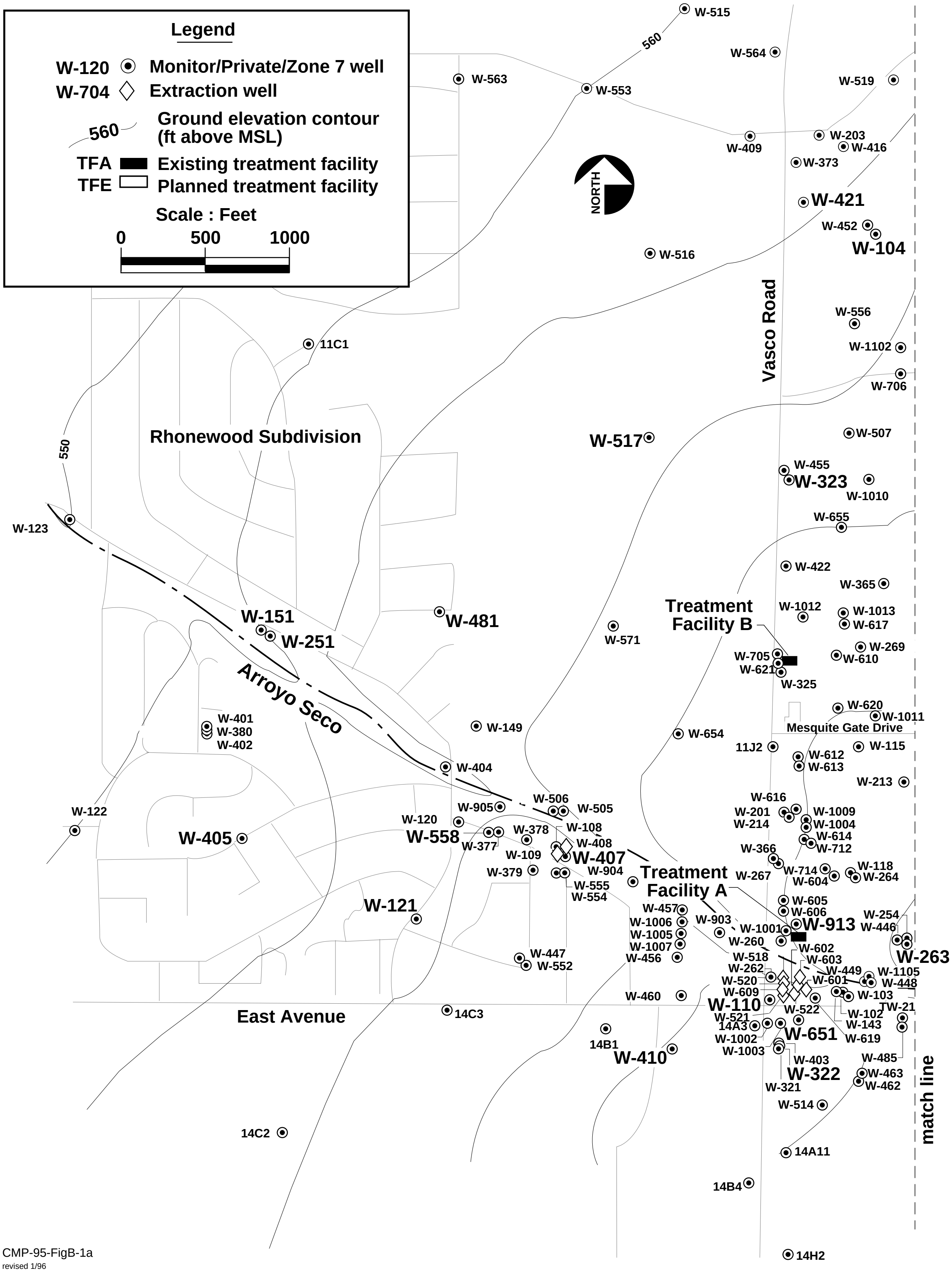
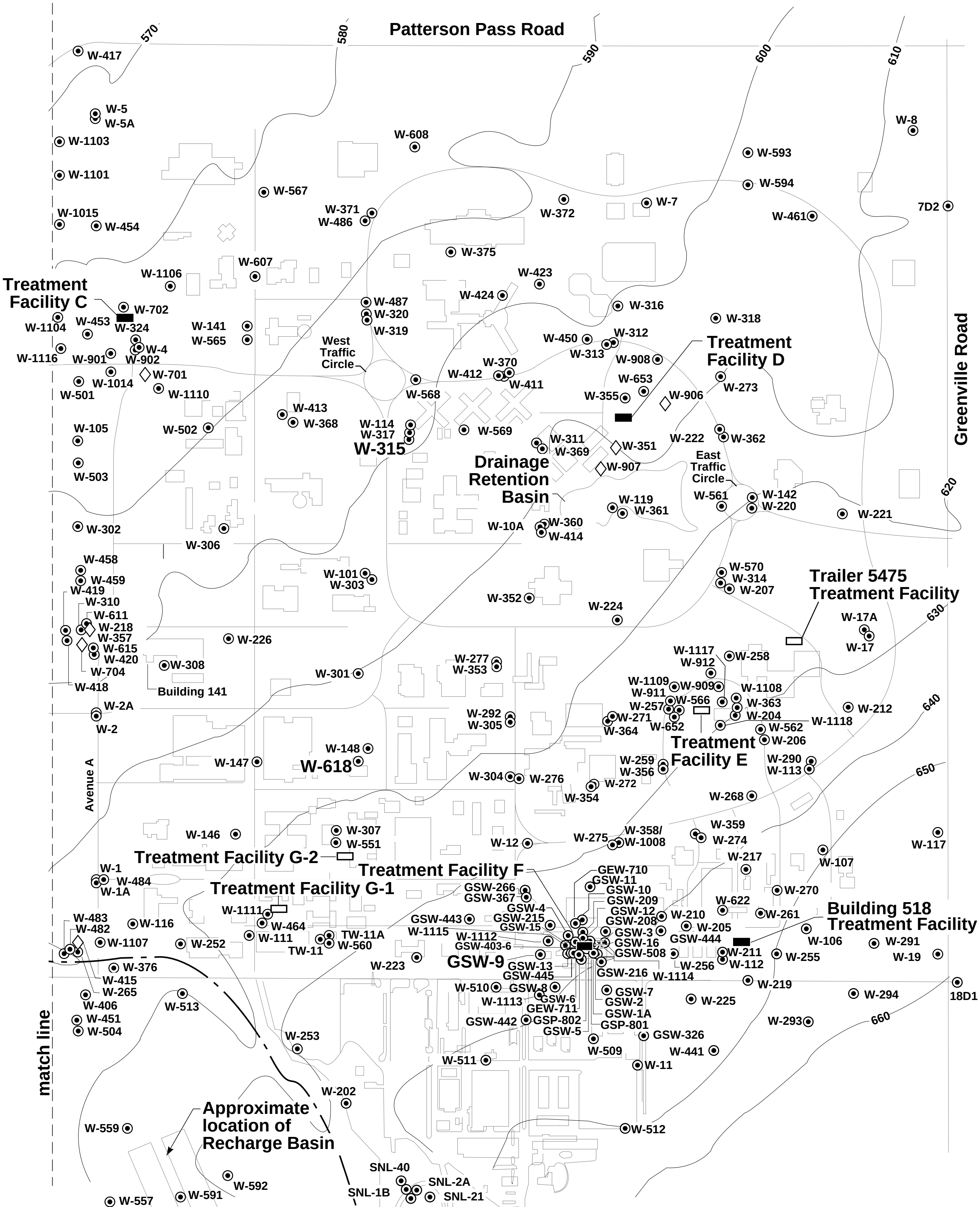


Figure B-1. Locations of Livermore Site monitor wells, extraction wells, and treatment facilities. Guard wells discussed in Section 3.1.1 are shown in larger type.



CMP-95-Fig B1b
revised 11/95j

Figure B-1 (continued).

Appendix C

Ground Water Monitoring Algorithm

Appendix C

Ground Water Monitoring Algorithm

C-1. Introduction

LLNL has been using a cost-effective sampling (CES) algorithm methodology to estimate the lowest-frequency sampling schedule for ground water monitoring locations that will still meet regulatory and cleanup monitoring needs. The CES algorithm bases initial sampling frequency recommendations on quantitative analyses of the trends and variability of VOCs at a given monitoring location. This algorithm applies to all existing and future wells. The following discussion is based on McConachie (1993), Johnson *et al*. (1995), and LLNL SOP 2.11, "Developing Ground Water Monitoring Sampling Schedule" (Goodrich *et al.*, in prep). The algorithm is a dynamic tool that will be modified as remediation continues and technical advances occur. Some planned enhancements for this algorithm are included in Section C-4 of this appendix.

Each LLNL well is sampled annually, semiannually, or quarterly. The method described below outlines the procedure to determine or revise the sampling frequency based on COC concentration changes and input from the FTL.

The sampling program is separate from the self-monitoring sampling schedule requirements in the California Regional Water Quality Control Board Waste Discharge Requirements for the treatment facilities.

C-2. The Algorithm

The sampling frequency for a given location is based primarily on COC trend, variability, and magnitude statistics. The underlying principle for the algorithm is that sampling frequency should depend primarily on the rate of recent change in COC concentrations. The higher the rate of change, whether up or down, the greater the potential need for more frequent sampling. Conversely, where little change is observed, less frequent sampling is warranted.

Variability in COC concentration is due to measurement uncertainty and natural heterogeneity and processes. Concentrations in wells exhibiting high variability may require a greater sampling frequency even though long-term rates of change (months to years) may be low.

The magnitude of the measured concentrations affects interpretations of the rates of change. A yearly change of 50 ppb is more significant for a well where the median concentration is 100 ppb versus 1,000 ppb.

Trends or rates of change are obtained by calculating the least-squares regression of concentration versus time. The slope of the line obtained by the least-squares regression analysis of the concentration versus time data for each well is used to determine the sampling frequency, as follows:

- The Annual category is for changes of less than 10 ppb per year.
- The Semiannual category is for wells exhibiting a moderate rate of change (greater than 10 ppb but less than 30 ppb) per year.
- The Quarterly category is for rates of change in excess of 30 ppb per year.
- Wells with less than 18 months of analytical history are sampled quarterly for the first 18 months.

The various steps in the CES algorithm are shown in Figure C-1, which is used to set the initial sampling frequency. Although not explicitly shown in Figure C-1, some locations will have sampling frequencies driven by regulatory or remedial needs instead of strictly following the algorithm. For example, wells located downgradient from the plume, west and south of LLNL, will remain on a quarterly sampling schedule to monitor for plume breakthrough. Ground water extraction wells associated with LLNL treatment facilities will also remain on a quarterly sampling schedule to calculate mass removal rates. The FTL may also adopt a sampling plan that differs from that determined by the algorithm. Such deviation from the algorithm would be determined by site specific needs, as discussed in Section C-3.

The algorithm frequency decisions are applied independently to each COC in a target list for a particular location. For the Livermore Site, the list currently consists of: carbon tetrachloride, chloroform, 1,1-DCA, 1,2-DCA, 1,1-DCE, 1,2-DCE, Freon 113, PCE, 1,1,1-TCA, TCE, and Freon 11. The sampling frequency assigned to a particular location is the most frequent of the schedules determined for the individual compounds.

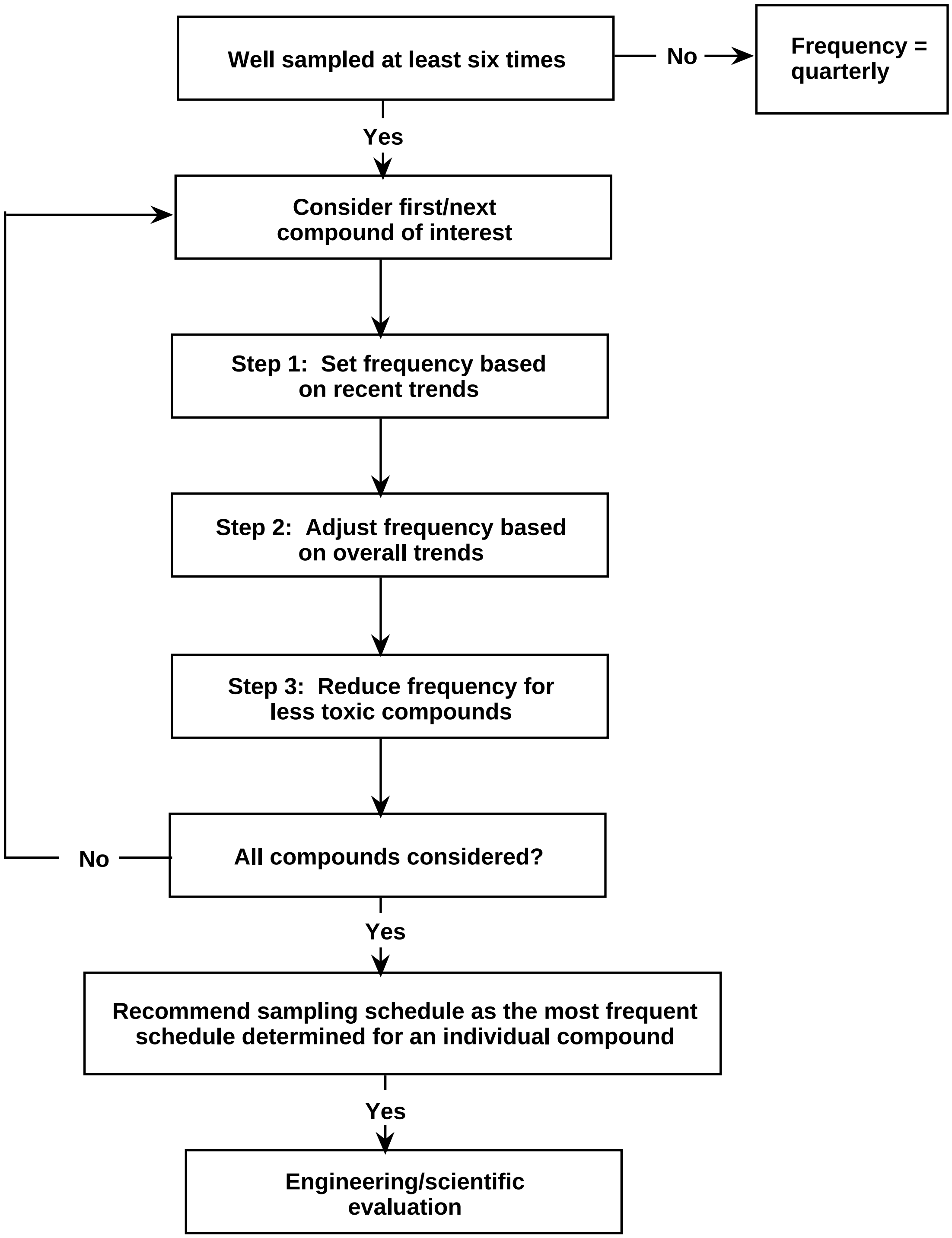
The evaluation of each COC proceeds in three steps: (1) an initial estimate of the sampling frequency is obtained by analyzing the most recent trend and variability information; (2) the recent trend is compared with the historical trend to identify cases where the results of Step 1 should be overridden based on overall statistics; and (3) a correction is made for the less-toxic substances on the list.

C-2.1. Step 1: Frequency Based on Recent Trends

The CES algorithm is based on rates of concentration change from the slope of a least-squares analysis regression line. The advantage of this statistic is its ease of interpretation because the slope can be expressed as a yearly change in concentration.

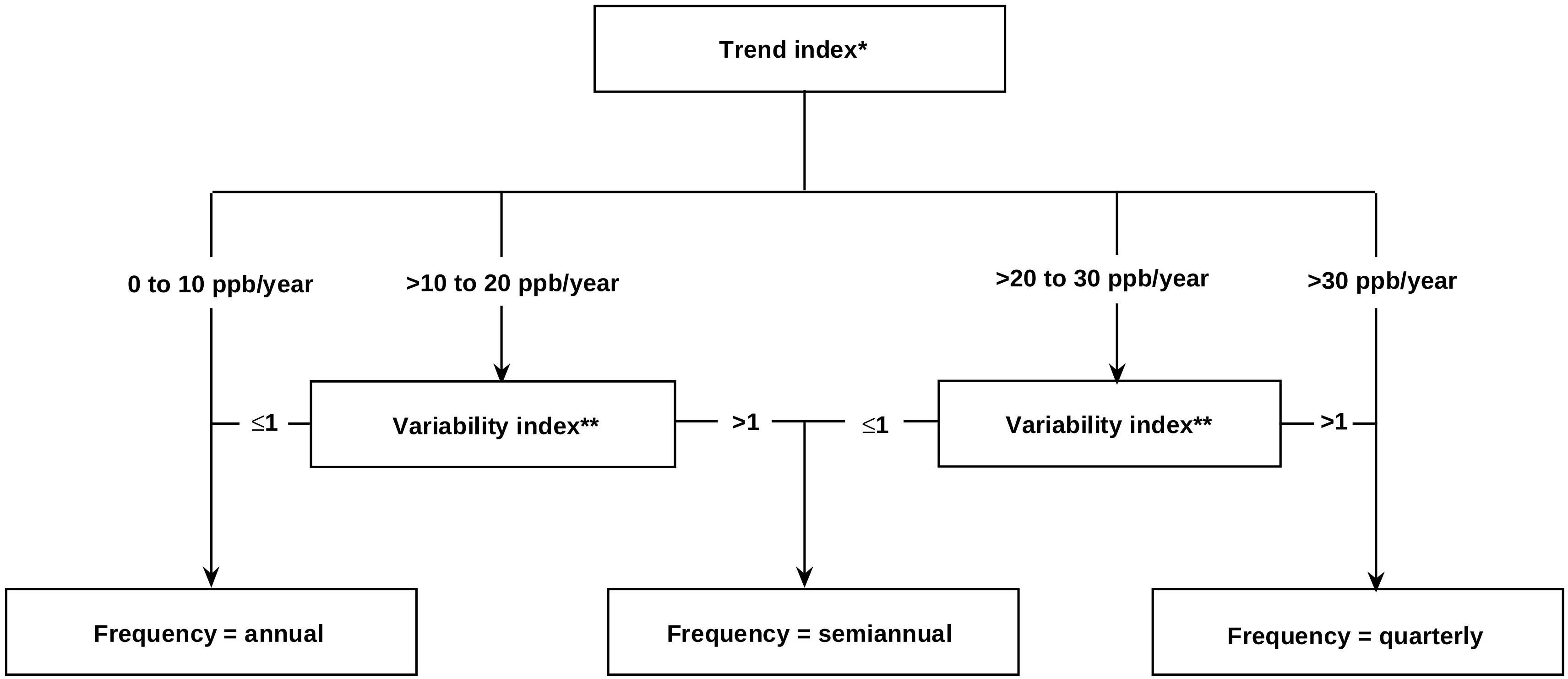
Rate, rather than direction of change, is the dominant factor in setting the sampling frequency. Based on the rate of concentration change, a well is routed along one of four paths (Fig. C-2). The lowest rate change, 0-10 ppb per year, results in an annual sampling frequency. The highest concentration rate change, over 30 ppb per year, results in a quarterly schedule. Rates of concentration change between these two extremes are qualified by statistical variability information, with higher variability resulting in higher sampling frequency, as discussed below.

Variability is characterized by a distribution-free version of the coefficient of variation: the range divided by the median concentration. This statistic corrects for the influence of concentration magnitude on variability at the Livermore Site. High variability is defined as a variability index greater than 1, and low variability is defined as a variability index less than or



CMP-95, Fig. C-1

Figure C-1. CES algorithm overview.



*** Least-squares slope in ppb/year obtained from the regression of time versus concentration.**
**** The coefficient of variation is obtained by dividing the range by the median concentration. See Section A-2.2 in text for more information.**

CMP-95, Fig. C-2

Figure C-2. CES Step 1 decision logic.

equal to 1. This threshold was derived empirically from LLNL data distributions and is the median statistical value calculated for the two most predominant COCs, TCE and PCE, across all locations in a benchmark dataset. Both the trend and variability statistics in Step 1 are calculated using data from the six most recent sampling periods.

C-2.2. Step 2: Frequency Adjustment Based on Overall Trends

While emphasis is placed on setting recommended frequencies from recent data, there are instances where a long-term history of change may override the Step 1 conclusion. The first three boxes in the Step 2 flow chart (Fig. C-3) reject cases where such a re-evaluation is trivial. The goal is to examine only those cases where the overall rate of change is significantly greater than the recent rate of change.

The major branch in Figure C-3 distinguishes two ways in which the long-term (overall) trend may be significantly greater than the recent trend. The right-hand side of the branch, which applies to most LLNL wells, is where the overall trend is greater, but not significantly greater than the recent (last 18 months) trend. For this case, the sampling frequency is re-estimated using Step 1 logic but with overall trends rather than recent trends. The left-hand side of the branch is the situation where the recent trend is similar to the overall trend. For this case, if the median concentration for the recent data is greater or equal to 10 ppb, the frequency will be determined by inspection. If the median concentration is less than 10 ppb, the sampling frequency will remain the same.

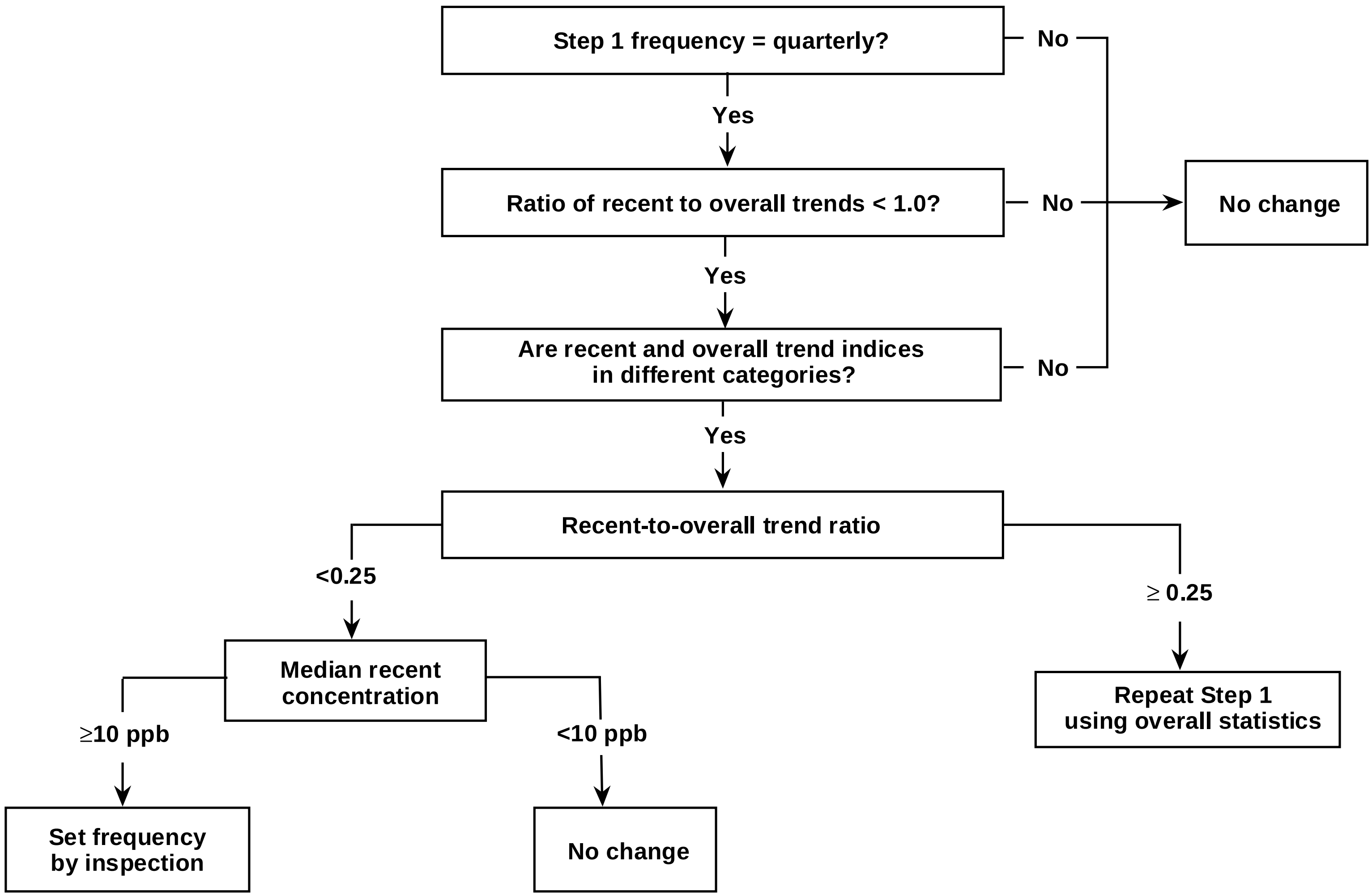
C-2.3. Step 3: Reduced Frequency for Less Toxic Compounds

Not all compounds in the target list are equally harmful. Because of differences in MCLs, an average trend of 25 ppb per year for TCE with a 5 ppb MCL is more significant than the same trend for chloroform, Freon 11, or Freon 113 with 100 ppb, 150 ppb, and 1,200 ppb MCLs, respectively. Currently, quarterly and semiannual sampling frequencies are reduced one level if the maximum concentration in the recent set of samples is less than half the MCL (Fig. C-4).

C-3. Discussion

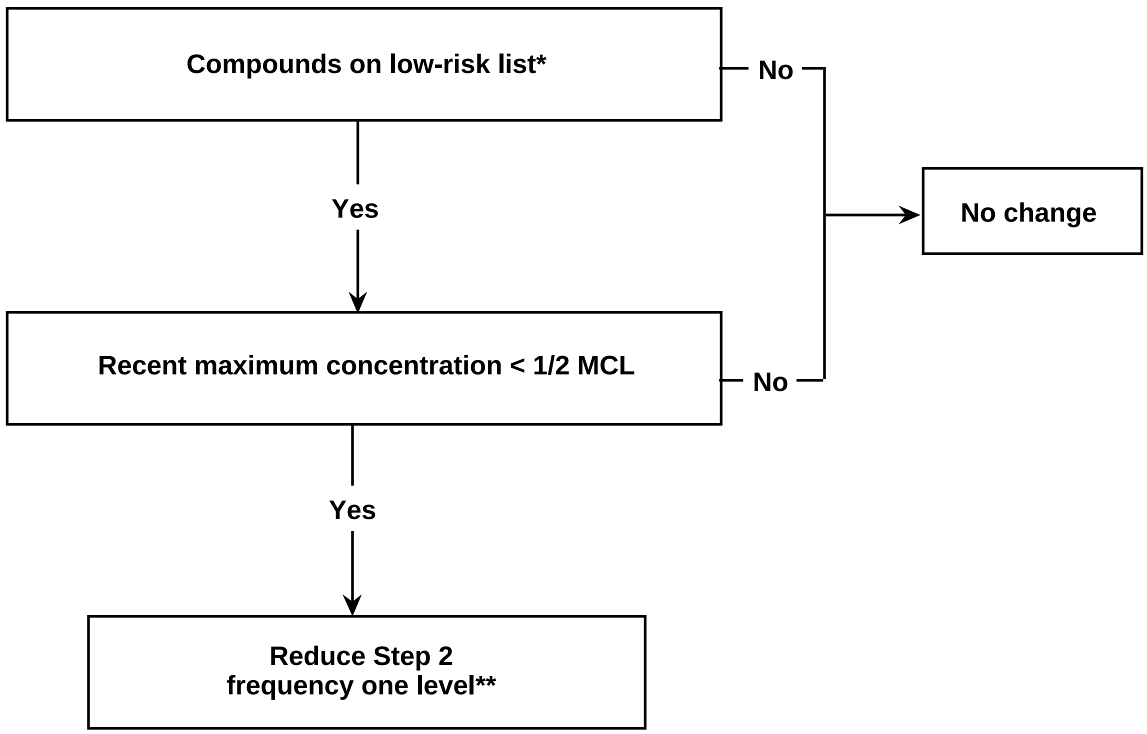
Each quarter, the CES algorithm is run and the sampling schedules are evaluated to monitor concentration changes in ground water. The sampling frequency is changed, if necessary, by evaluating the overall and recent history of each well.

The FTL is responsible for tracking, analyzing, and monitoring analytical data trends for each well associated with the ground water treatment facility. The FTL can request that the Sampling Coordinator run the algorithm at any time, or revise the sampling plan from that produced by the algorithm. The FTL can add or delete wells from the sampling list based on the algorithm results and the special needs of the facility (e.g., startup testing). The FTL also considers variables that are not addressed by the algorithm, such as well type and location within or near the plume. Wells located downgradient from the plume (i.e., to the west and south) will remain on a quarterly sampling schedule to verify plume containment. Ground water extraction wells associated with LLNL treatment facilities will also remain on a quarterly sampling schedule to estimate mass removal rates.



CMP-95, Fig. C-3

Figure C-3. CES Step 2 decision logic.



*** Chloroform, Freon 11, Freon 113**
**** Quarterly to semiannual; semiannual to annual**

CMP-95, Fig. C-4

Figure C-4. CES Step 3 decision logic.

TFF is not presently included in the schedule revision process because of ongoing investigations in this area. However, when the operation stabilizes, the TFF FTL may elect to use the algorithm to provide an alternative sampling schedule for all or some of the existing monitor wells and piezometers.

A summary of VOC analyses is available on an annual basis. Ground water elevation contour maps showing estimated capture zones for extraction wells will be prepared quarterly or annually as discussed in Section 3.2.1 of the text. Ground water sampling frequencies for each well will be presented annually in the LLNL Ground Water Project Annual Report.

C-4. Future Algorithm Enhancements

The algorithm is a useful tool for making decisions concerning ground water monitoring frequency. Additional decision factors will be incorporated into the algorithm in the future to provide even more information to the user and allow the algorithm to be applicable to a wider variety of sites. Planned improvements for the algorithm are discussed below.

- The current algorithm is excellent for making decisions on low concentrations of VOCs in ground water. However, at high concentrations (>300 ppb), the algorithm, which examines the slope of the regression line may recommend unnecessarily high sampling frequencies because the concentration fluctuations at high concentrations can be large. Therefore, at concentrations greater than 300 ppb, instead of using a specific concentration limit, the algorithm will be modified to use the percentage change in concentration compared to the mean value of the data when determining the appropriate sampling frequency.
- The algorithm will provide a specified flag to indicate to the user whether a well is above or below the MCL for the COCs.
- As the cleanup progresses, concentrations are expected to decrease for an extended period. For wells with decreasing concentrations, especially at the center or upgradient margin of a plume, a lower frequency of sampling such as once every 2 to 5 years, or perhaps discontinuing sampling altogether, may be more appropriate. The algorithm will examine the rate of the decrease of the COC and will recommend a more reasonable sampling frequency.
- Presently, the algorithm does not take into account the location of the well relative to plume boundaries, source areas, etc.; it examines the well as a single point. Addition of the well location as a factor will allow direct contouring of the data, and will allow well redundancy to be assessed. Well redundancy is two or more wells that monitor the same zone (or HSU) in close proximity to one another and provide similar monitoring data. If the data are similar for two or more nearby wells completed in the same interval, then the monitoring of one or more wells could be reduced or discontinued as a cost-savings measure.

C-5. References

Goodrich, R., S. Hassan, G. Howard, and G. Kumamoto (in preparation), *"Developing Ground Water Monitoring Sampling Schedules," Environmental Restoration Division Standard Operating Procedures*, Lawrence Livermore National Laboratory, Livermore, Calif.

Johnson, V. M., M. N. Ridley, and R. C. Tuckfield (1995), "Cost-effective Sampling of Groundwater Monitoring Wells," in *Proceedings*, *Hazardous Materials Management Conference and Exhibition*, San Jose, California, April 4-6, 1995, p. 14-21.

McConachie, W. A. (1993), Division Leader, LLNL Environmental Restoration Division: letter to M. Gill of U.S. Environmental Protection Agency, B. Cook of the Department of Toxic Substances Control, and S. Ritchie of the Regional Water Quality Control Board, describing the sampling schedule for the LLNL Livermore Site monitor wells, dated February 10, 1993.

Appendix D

Soil Vapor Monitoring Algorithm

Appendix D

Soil Vapor Monitoring Algorithm

D-1. Introduction

This appendix describes the algorithm used to develop and maintain soil vapor sampling schedules for the Livermore Site. The sampling frequency for a given location is based on trend, variability, and magnitude statistics for the COCs at that location. The underlying principle for the algorithm is that sampling frequency should be recommended primarily by the recent rate of change in COC concentrations. Greater changes may result in more frequent sampling. Conversely, where little change is observed, less frequent sampling is appropriate. This methodology estimates the lowest-frequency sampling schedule for a given soil vapor monitoring location that will still meet regulatory and cleanup needs. The algorithm is a dynamic tool that will be modified as remediation continues and technical advances occur. Some planned enhancements for this algorithm are included in Section D-3 of this appendix.

Soil vapor samples will be collected from vapor extraction wells and probes. This algorithm applies to both existing and future wells and probes. This sampling program is separate from the discharge self-monitoring maximum, established by the Bay Area Air Quality Management District, of 6 parts per million (ppm) on a volume-to-volume basis total VOCs.

The sampling frequency for each soil vapor extraction and monitoring location will be either quarterly, monthly, or weekly. This appendix outlines a procedure to determine, and revise when necessary, the soil vapor sampling frequency based on COC concentration history, change in concentration, and input from the FTL.

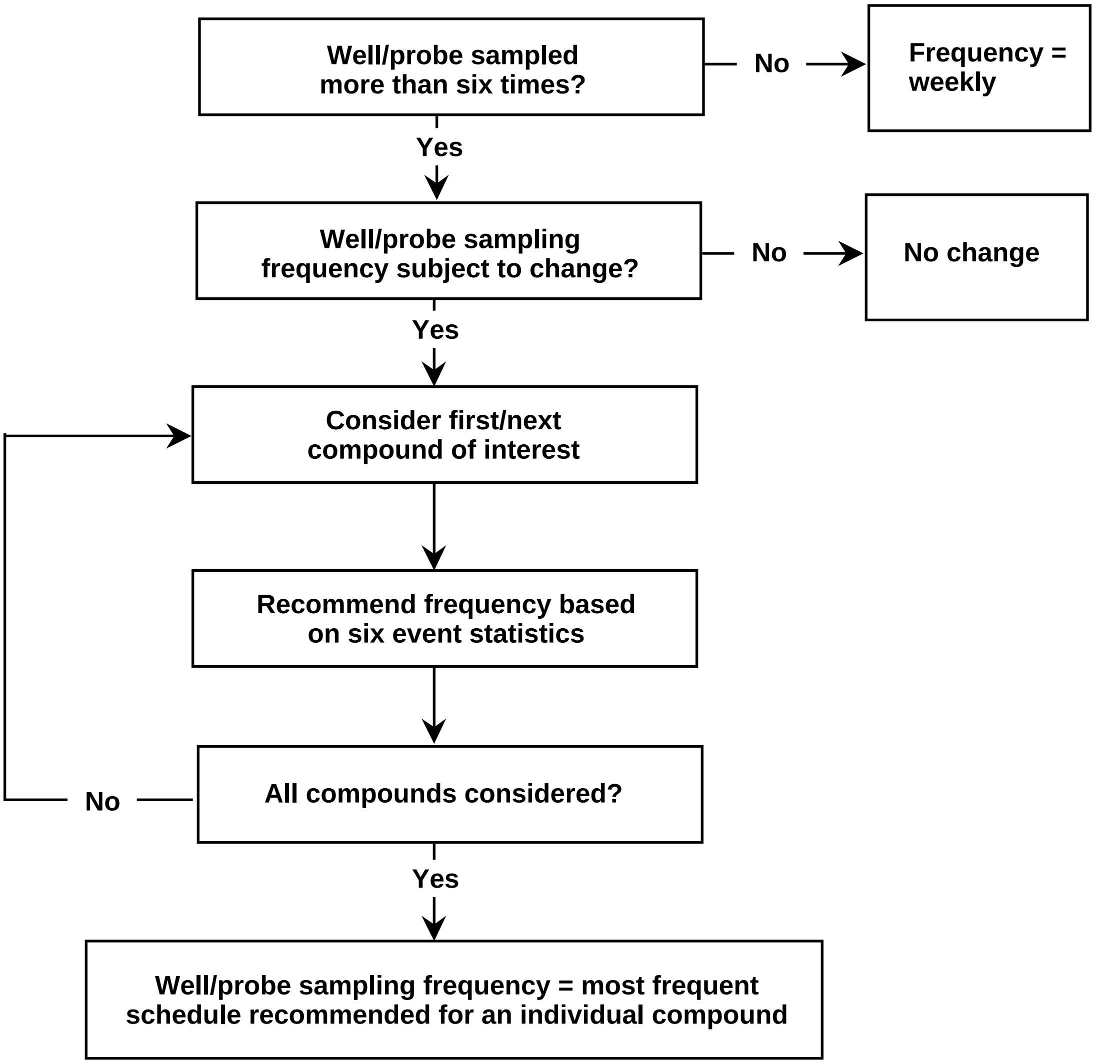
D-2. The Algorithm

The vapor sampling schedules will be evaluated prior to sampling to monitor COC concentration changes. The sampling frequency will be determined, by evaluating both recent (last six sampling events) and historical concentration data for each well or probe. The various steps in the algorithm are shown in Figure D-1.

The FTL will analyze and monitor chemical data for each soil vapor extraction and monitoring location prior to each sampling event. The FTL will review the results of the algorithm for each location to determine if the sampling frequency should be altered.

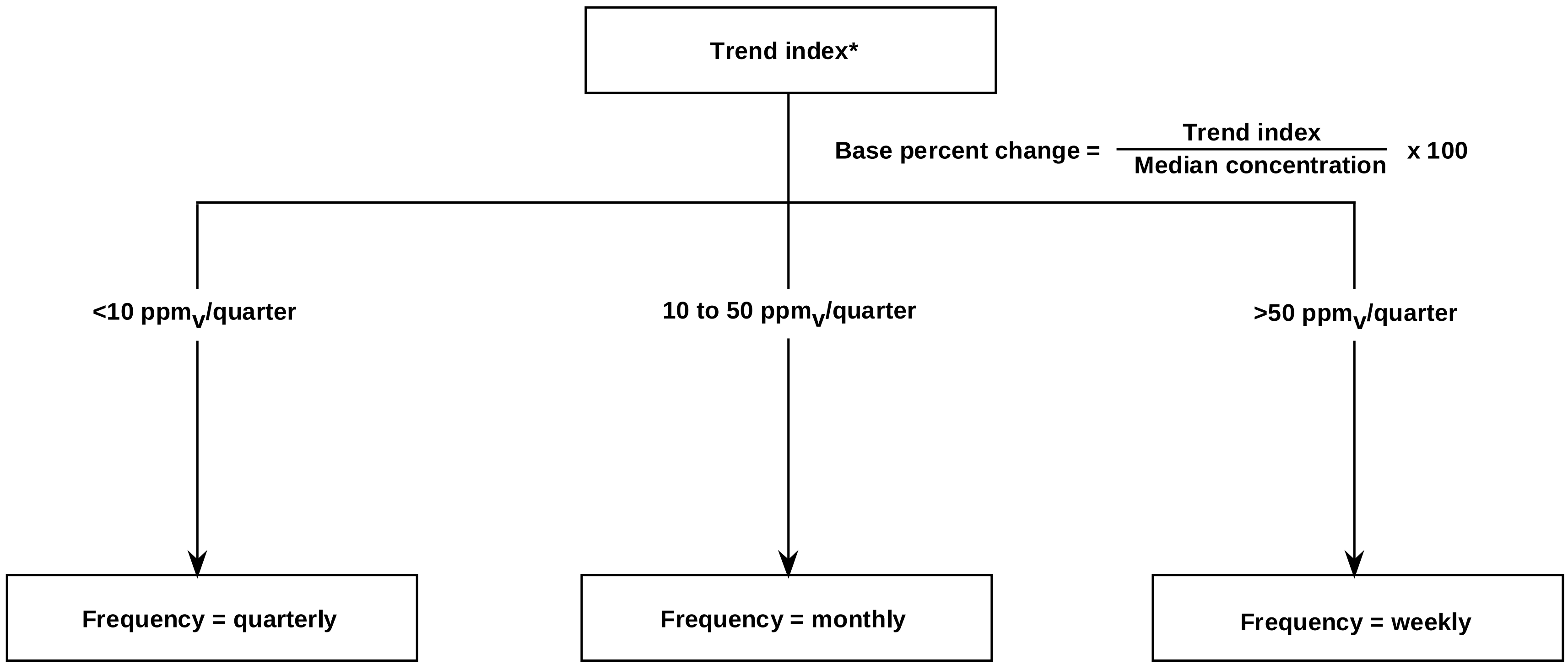
Trends or rates of change will be obtained by calculating the least-squares regression of concentration versus time. The slope of the line obtained by the least-squares regression analysis of the concentrations versus time data for each well will be used to determine the sampling frequency as follows (Fig. D-2):

- The Quarterly category is for trends of less than 10 ppm by volume per quarter (ppm_V/quarter).



CMP-95, Fig. D-1

Figure D-1. Soil vapor monitoring algorithm overview.



* Trend index is defined as the slope of the line obtained by a least-squares regression analysis of concentration versus time for each well or probe.

CMP-95, Fig. D-2

Figure D-2. Soil vapor monitoring decision logic.

- The Monthly category is for soil vapor monitoring locations exhibiting a moderate rate of change (10 to 50 ppm_V/quarter).
- The Weekly category is for rates of change in excess of 50 ppm_V/quarter.
- Soil vapor monitoring locations with less than 6 weeks of analytical history will be sampled weekly for the first 6 weeks; then the algorithm logic (Fig. D-2) will be used to determine the sampling frequency.

D-3. Future Algorithm Enhancements

The algorithm is a useful tool to make decisions concerning soil vapor monitoring frequency. Additional decision factors will be incorporated into the algorithm in the future to provide even more information to the user and allow the algorithm to be applicable to a wider variety of sites. Planned improvements to the algorithm are discussed below.

- The algorithm is excellent for making decisions on low concentrations of VOCs in vapor. However, at high vapor concentrations, the algorithm, which examines the slope of the regression line, tends to recommend unnecessarily high sampling frequencies because the concentration fluctuations at high concentrations can be large. Therefore, at concentrations greater than approximately 100 ppm_V, instead of using a specific concentration limit, the algorithm will use the percentage change of a concentration compared to the mean value of the data when determining the appropriate sampling frequency.
- As the cleanup progresses, concentrations are expected to decrease for an extended period. For wells or probes with decreasing concentrations, a lower frequency of sampling may be more appropriate, such as once every 1 to 2 years. The algorithm will examine the rate of the COC decrease and will recommend a more reasonable sampling frequency.

D-4. Discussion

The FTL is responsible for tracking and analyzing the trends of sampling results for each soil vapor monitoring location associated with a vapor treatment facility. The FTL revises sampling frequencies, and can add or delete soil vapor monitoring locations based on the algorithm trend results and the special needs of the facility (e.g., startup testing). The FTL may adopt a sampling plan that differs from that determined by the algorithm. The FTL also considers variables that are not addressed by the algorithm, such as probe type and location within or near the plume. Vapor extraction wells associated with LLNL treatment facilities will remain on a weekly sampling schedule to estimate mass removal rates unless less frequency is agreed to by the regulatory agencies. A summary VOC vapor chemical analyses will be provided quarterly.

Appendix E

Reporting Requirements

Appendix E

Reporting Requirements

E-1. Requirements

DOE/LLNL will provide the regulatory agencies the following documents according to the timetable presented in Table E-1.

Table E-1. Reporting requirements.

Report	Elements	Deadline
Monthly RPM meeting summary	• Compliance issues • Facility status update • Work performed • Work anticipated • As-needed, data may include the following: - Comparison of predicted and measured performance - Updates to the conceptual and computational models - Source investigation results - Proposed changes to the remediation plan - Progress of cleanup - Identification of potential problems which will threaten to cause delays of documents or activities	**Variable; approximately 30 days after the subsequent RPM meeting**
Quarterly report	• March, June, September, or December RPM summary • Quarterly self-monitoring data for treatment facilities and the Drainage Retention Basin[a] • Monthly water or vapor quantities extracted, and quarterly VOC mass removed by treatment facility • Ground water contour and capture zone maps by hydrostratigraphic units of interest	**Within 60 days of the end of the reporting period**
Annual report	• Field investigation summary • Remedial action program summary • Regulatory compliance, documents issued, and milestones achieved summary • Trends in analytical results • Well construction and closure data • Hydraulic test results • Ground water sampling schedule • Isoconcentration contour maps by relevant hydrostratigraphic unit • Comparison of isoconcentration contour maps to model calculations[b] • VOC mass removal graphs for treatment facilities	**By March 31 of the following year**

[a] **ERD currently includes a quarterly summary of the Drainage Retention Basin by the Operations and Regulatory Affairs Division.**

[b] **Beginning with the 1996 Annual Report.**

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